DEPARTMENT OF
SCIENTIFIC AND INDUSTRIAL RESEARCH

Automation

A report on the technical trends and their impact on management and labour

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Acknowledgements of photographs and drawings are given individually in captions, wherever appropriate.

Preface

AUTOMATION is a new word for what is both old and new. This is why the use of the word is somewhat confusing. Those who think in terms of an evolutionary growth of labour saving mechanical and electronic devices in business offices and production shops show some irritation at an unnecessary new word and an ugly one at that. But the development and application of the automatic electronic computer — commonly known as the "electronic brain" — for the integration and control of office procedures and manufacturing processes is something new, beckoning us towards the electronic office and the automatic factory of which we can already see the outlines. Automation is a fabric of many strands which is still in the making and the purpose of this survey is to describe the technical nature of the strands and to indicate the texture of the industrial fabric that is being woven.

The urge behind automation is economy of operation and production, expressing itself not only in a more effective use of human effort but also in a greater precision and reliability of working than can be obtained by other means. But the solution of the complex technical problems involved and the definition of the operational procedures inherent in the new methods of working depend not on machines but on the use we make of our human resources, in particular on the training we are prepared to give and undergo. Automation will not make robots of us all. On the contrary it will demand wider knowledge, greater ability and a higher degree of skill from worker and manager alike.

In addition to the factual information provided, this short survey will, it is hoped, stimulate thought and direct attention to certain social and economic implications of automation. Much here is problematical and it would be foolish to dogmatize. In human affairs the unexpected is to be expected and many obvious difficulties may never occur. But these are no reasons for withholding serious thought or for neglecting vigorous research and systematic study of the material and human problems involved.

B. LOCKSPEISER
Secretary

9 *March* 1956

Contents

Figures

Each reference in the text is indicated by a number in brackets, which relates to the item so numbered in the list of references in Appendix IV on page 92.

CHAPTER I

Automation in Perspective

AUTOMATION, though a convenient term, is difficult to define because it has several different meanings in popular usage. It is used in this Report so as to include all technical developments that make automatic production more possible. The ultimate state of a completely automatic factory or office is described as "full automation".

This usage conforms to what has been widely accepted since automation became a topic of discussion a few years ago. It implies, correctly, that automation is not a new phenomenon. (Indeed its origins are in the early days of the Industrial Revolution). Equally it implies that automation is not a single, easily identified development, but a confluence of the following independent streams of technical progress:

1. The expansion of the scope of mechanization by transfer-devices that link machine-tools in automatic production-lines; and by advanced techniques of handling materials and products and of assembling components.

2. The rapid development of techniques of automatic control over manufacturing processes and their application to an ever-widening range of industries.

3. The rapid and automatic processing of an increasing range of technical and business information by the electronic digital computer, with a consequent extension of automatic control to complex manufacturing operations and commercial offices.

Recently progress has been rapid in all three directions and in future it may be even faster, especially in the control of manufacturing operations by computers. In theory automatic control can be extended from individual operations to whole processes and ultimately to complete factory systems. It is already possible to envisage a large and complex, yet fully automatic factory in which a computer integrates and controls the separate automatic production lines. This possibility is the most important new element in automation, even though it cannot be realized immediately. In future, units incorporating computers will almost certainly contribute the most striking developments in automatic control: they will be the outcome of continued progress in electronics and of improved knowledge of the processes it is intended to control.

HISTORICAL PERSPECTIVE

AUTOMATION AND MECHANIZATION

In so far as automation replaces human muscle by mechanical power, it continues a process of mechanization which began before the Industrial Revolution two centuries ago. The first machines were not automatic: they performed many physical tasks but they had to be operated and controlled by workers. But semi-automatic machines were invented early in the history of mechanization; there were, for instance, the textile machines used in carding, drafting, spinning and weaving and, later on, the lathes widely employed in engineering. These machines performed automatically, once they were set and loaded, and they confined the human operator

to two kinds of work; the unskilled work of loading and unloading, and the skilled work of setting and maintaining machines.

Since then technical developments have been gradual and continuous. They have greatly widened the range of operations that can be performed automatically and they have mechanized some loading and unloading of machines. Perhaps the best and most recent instance is the transfer-machine in engineering; it combines automatic machining with automatic transfer between operations, so that all loading and unloading is done mechanically except at the beginning and end of the line. There have also been extensive developments in the handling of materials and components between processes and in the mechanical assembly of simple components.

AUTOMATIC CONTROL

Automatic control is also as old as the Industrial Revolution. Its use was confined to mechanical gadgets at first, but was later extended to industrial processes. The pace of technical development was slow but steady until the last war, when it was quickened to meet military needs.

The purpose of controlling processes is to maintain a continuously high quality of product by minimizing the effects of variable conditions in the process or plant. Initially control was obtained by a human operator, who noted faults or deviations and corrected them either directly or through instruments. Automatic systems take several forms and are based on several different techniques, but in each case the measurement and correction of errors are performed and co-ordinated by mechanisms and the human operator has only to supervise the operation or process; he does not take an active part in it.

Automatic control is widespread in the petroleum, chemical and other fluid-processing industries, but it also exists in a large variety of other processes. Among the many physical properties than can be controlled are the gauge of steel sheet in continuous rolling mills, the thickness of insulation around electric wires, the oven-temperature in the baking of biscuits, moisture-content in textiles, and temperatures and pressures in chemical processes.

AUTOMATION AND ELECTRONICS

Electronics has made two main contributions to automation: it has extended the range of automatic control and it has made the processing of information rapid and automatic. Electronic devices respond very quickly to signals and take measurements and detect faults very accurately; so they can effectively control many processes and machines that must work at high speeds. When computers form part of an automatic control system, they extend its scope to complex operations such as machining components of complicated shape. Finally, electronic control gear can very easily be placed as a distance from the operations. Large areas of plant can be centrally controlled—in power stations and chemical works, for instance—and human operators can work in safe and congenial surroundings.

Electronic digital computers, though built initially for mathematical work in science and technology, have been applied to industrial problems in the last few years and have already shown themselves capable of doing routine clerical work so different as the working out of pay-rolls and the reservation of seats in aircraft. The main technical principles are firmly established and further progress depends chiefly on a detailed study of existing procedures in all types of office in order to extend the

economic uses of computers. Ways are also being sought of using computers to integrate the automatic control of individual processes and to frame and vary production policies. It is the possibility of such integration that makes the concept of an automatic factory a serious topic for thought and discussion.

A CONCEPT OF AUTOMATIC PRODUCTION

In a typical automatic factory there are five basic requirements; essential working operations, inspection, handling, assembly and central control should all be automatic. Figure 1 outlines one possible scheme: it illustrates a simple engineering factory, but the principles hold good for any industry.

All operations in this imaginary factory are centrally regulated by a master production-controller under the direction of the management. A computer, which forms part of the control unit, analyses information about sales, orders and changes in the market and this information, combined with policy information provided by the management, gives the basis of each plan for production. For the sake of simplicity Figure 1 shows only three production-lines and two assembly-points. The master production-controller releases material from the stores as it is needed and keeps an optimum load on the automatic machine-tools in each line. Similarly it releases the finished components at appropriate intervals to the assembly-line, where they are automatically put together and packed for despatch.

The machinery in each process—machining, inspection, assembly and packing—is regulated by subsidiary controllers, and each controller is directly linked with the master, which conveys information to it as a basis for adjustments—for instance, information about the quality of the product as a basis for regulating the settings of machines and other plant.

Even in this fully automatic factory manpower is still necessary to mind and maintain machines, to do some of the clerical work and to perform the many functions of management. But the traditional teams of operative labour, directly engaged on the process have disappeared.

How easy it will be to make a factory automatic depends on the nature and variety of work done in it. Where simple products or parts are made, and where handling and assembly are straightforward, production could be virtually automatic now. But most factories have several processes and difficult problems of operation. Many materials and parts have to be handled and they are often of diverse or complicated shape. Products have to be inspected, sometimes by making subjective judgements on the basis of long experience. The assembly of components usually requires manipulative skill. In these factories automation must come by stages and in many of them full automation will be uneconomic.

If the present state of automation is set against the five basic requirements of a fully automatic factory, as conceived in Figure 1, it is possible to see what developments have yet to be accomplished and how far they can be expected to result from existing technical trends.

ESSENTIAL WORKING OPERATIONS

In the metal-cutting industry further progress relies on the development of automatic machine-tools. Transfer-machines will be increasingly used in mass-production, the limit depending on how flexible they can be made; but the control of machine-tools by computers will probably make most headway in prototype-building

and small-quantity production. In the long run techniques of automatic control will probably be extended to long and short production-runs and many machine-tools may be automatically adjusted so as to follow a set programme of operation. The setting and replacement of tools will also need to be automatic. As a first step, batteries of pre-set tools may be changed automatically according to a fixed programme—as has already been done on an automatic lathe.

Automatic control has made rapid progress in the chemical, petroleum and other fluid-processing industries, but it has been confined mainly to simple physical characteristics and has yet to be extended to more complicated matters, such as the chemical composition of raw materials. Possible methods are already being developed, for example automatic chemical analysis.

INSPECTION

A number of simple variables, like the dimensions of components, can already be automatically tested by mechanical, pneumatic, optical or electro-mechanical instruments, and it is becoming possible for instruments to detect flaws, sort components and identify shapes. But more difficulty is experienced with the inspection of chemical properties or of the more complicated physical properties like viscosity and turbidity, though some promising instruments are being developed.

HANDLING

Automatic handling has made much progress in recent years. There are now no difficult technical problems in moving fluids during processing and there is a variety of new equipment for handling solids, for example gravity-feeders for machines, gravity and vibratory conveyors, and powered conveyors. Also many solids are being made to move like fluids, either by dissolving or suspending them in fluids, or by pumping them along pipes and channels, or by making them into a paste, or by "fluidizing" them—that is to say by dividing them so finely that they behave like fluids.

It is more difficult to move the large solid shapes that abound in engineering factories, but already some of them are automatically transferred from one tool to the next and automatically handled between production-lines. The flow of materials and parts through a factory is still co-ordinated by human operators; but it can also be, and occasionally is, controlled by electronic computers. Many of these techniques are at an early stage of development, but their use is likely to be extended gradually in the near future.

ASSEMBLY

Some progress has been made with automation in simple assemblies, but the general prospect is still uncertain. One useful development is the automatic marshalling of parts for assembly, as at the Longbridge factory of the Austin Motor Company. There are also many mechanical devices that bring and fix components of simple shape together; they are used, for instance, in the assembly of wooden doors, chassis-frames and engine parts, the capping of bottles, and the manufacture of electric lamps. Their scope and use will probably be increased in future. In fine assembly, which requires delicate manipulation and adjustment, the human being still has an advantage over the machine, but automatic control-mechanisms may be used in

future to simulate some of the trial-and-error movements normally done by human bands.

The most likely development is that automatic assembly will he made much easier by the re-design of products and the re-arrangement of processes, so as to cut out much manipulative skill. This has actually happened in the assembly of electrical circuits for radio and television sets. Only human hands can assemhle a conventional circuit, which is made with a complex system of wiring, hut it is already possible to print or etch a circuit on an insulating hase and have it produced by automatic machines. Assemhly becomes a simple matter of inserting components, sucb as resistors and condensers, in the circuit board, and it can be done mechanically. Again, re-design of motor-vehicle engines has made it possihle to tighten bolts automatically on the assembly-line.

CENTRAL CONTROL

Automatic control of individual processes is widespread in a number of industries and in some factories there is simple integration of control. But nowhere has integration heen extended to wbole systems of production, though it is possible to envisage that bappening with the help of a computer. In the imaginary engineering plant sbown in Figure 1 a computer plans production according to orders received and expected hy the sales department and sets and changes the programmes of machine-tools and of their associated control-mecbanisms. It also does the routine clerical work of the factory.

How far control by computers will develop depends on experience gained in using them first for simple, and later for more difficult tasks. In the near future they may be used to control individual production lines or part of a process, and they will certainly help managements to control production hy analyzing information quickly; but they will not exercise control directly on the basis of their own calculations. In the more distant future the possibilities of development are so great that computers may take over much detailed work of management and so increase the efficiency of its control.

CONCLUSION

The pattern and technical basis of full automation can he seen in terms of new developments in production—transfer-machines, mechanical handling and assembly, automatic control of machinery and processes, and clerical work by electronic computers. Where two or more developments have converged, the near-automatic factories are generally to be found, and two interesting examples—a piston factory in the USSR and a British factory making huilding boards—are described in the last pages of this chapter. But current progress towards automation is mainly in separate streams; it helps to make more processes automatic but it does not integrate them and so does not fulfil the concept of fully automatic production. Tbe present state of automation is hest discussed in terms of the separate trends, as in Chapter II.

EXAMPLE 1. A PISTON FACTORY IN THE USSR

(combining transfer-machinery with mechanical handling and automatic process-control)

A nearly automatic piston factory has, it is claimed, heen established in the USSR (Figure 2.)[130] It has two production-lines, each of which produces one of the two

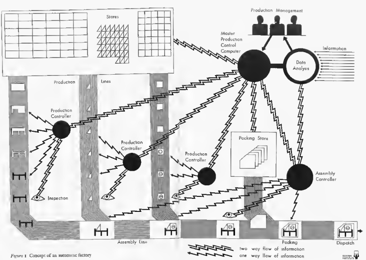

Figure 1 Concept of an automatic factory

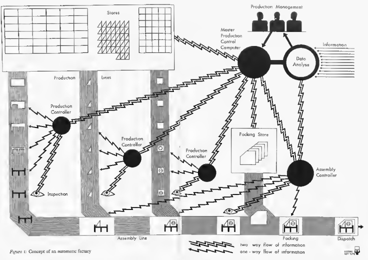

Figure 1: Concept of an automatic factory

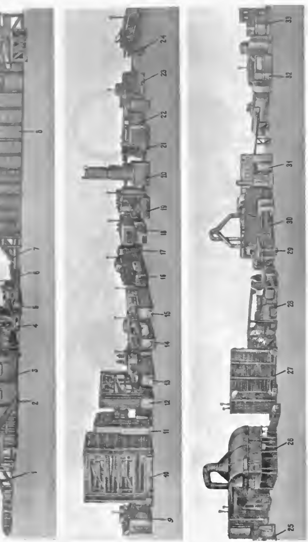
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Figure 2. Piston Factory (U.S.S.R.)

1 Conveyor for feeding aluminium ingots to the smelting furnace.
2 Scraper-conveyor for feeding sprues to the furnace.
3 Electric smelting oven.
4 Six-position carousel casting machine.
5 Milling-machine unit for cutting off sprues.
6 Transporter.
7 Slatted conveyor feeding the heat-treatment oven.
8 Electrically heated oven for heat treatment.
9 Automatic press for the determination of hardness.
10 Storage-bunker for moving blanks.
11 Aggregate for machining the basal surfaces.
12 Storage-bunker supplying the automatic machine-line.
13 Two-position machine for preliminary boring of the hole for the piston pin.
14 Multi-cutter lathe aggregate for final machining.
15 Milling-machine aggregate for cutting horizontal grooves.
16 Multi-cutter lathe aggregate for final machining.
17 Automatic gauging unit for testing the height of the pistons and the width of the piston ring grooves.
18 Twin machine for boring oiling holes.
19 Two-wheel circular grinding machine.
20 Twin machine for milling the inclined slots and cutting off the central boss.
21 Pneumatic table for lowering the platens.
22 Load-transporter (fractional conveyor).
23 Five-position automatic unit for adjusting the weight of the pistons.
24 Transporter.
25 Four-wheel centreless honing machine.
26 Automatic conveyor system for tinning the pistons.
27 Storage-bunker
28 16-spindle machine for the final machining of the hole under the piston pin.
29 Table for pistons.
30 Washing machine.
31 Automatic checking and sorting unit.
32 Automatic packing machine.
33 Control desk.

standardized pistons and can also produce over-size pistons for overhaul purposes. At one end of the factory, aluminium-alloy pigs are loaded on to a conveyor, which discharges them into an electric melting furnace as required, the amount fed in being controlled by the amount drawn off. The molten metal is refined by a continuous chloride blast and then passes to an automatic die-casting machine, equipped with an automatic core-loading device. The casting moves to another machine which cuts off the gate and head and cleans up the boss at the end of the skirt. The gate and head fall on to a conveyor belt, which takes them back to the furnace. The piston casting goes through a continuous heat-treatment furnace, after which it is cooled in an air chamber and passed to an automatic press, where its hardness is tested, the diameter of the impression being measured by an electric contact head. Pistons that are too soft are automatically rejected into a scrap bin; the remainder move on to an automatic store, which is necessary because the casting and heat-treatment sections of the factory work round the clock, while the machining sections which follow have to be shut down in the third shift for the maintenance of machines.

The automatic machine-line has three important features: high-speed drills driven by high-frequency induction motors; automatic devices which disconnect the drive to any tool that is absorbing too much power because it needs resharpening; and multi-spindle grinding machines. Automatic gauging is employed throughout and a machine-tool is stopped as soon as it produces a reject.

After machining the pistons pass to an automatic weight-correcting machine, which removes metal from interior bosses until the weight is within acceptance limits. The pistons are then fed automatically into a centreless polishing machine, a degreasing bath, a hot and cold water wash, a plating bath, another cold water wash, and a final hot water wash. The pH value of the electrolyte in the tin-plating bath is kept constant automatically by the addition of acetic acid.

After air-blast cooling, the pistons go through another automatic store to a machine which finish-bores the transverse holes for the gudgeon-pins to a limit of 10 microns, and drills the oil drain holes at the bottoms of the scraper ring grooves. From here, the pistons pass through an automatic washing machine, after which they are automatically gauged for skirt taper and diameter, and for the gudgeon-pin bore height, squareness and diameter. The gudgeon-pin bosses are automatically marked to indicate the dimension-groups into which the pistons fall on the basis of skirt diameter and gudgeon-pin bore diameter. The temperature at the washing machine is automatically controlled, so that all gauging is done at a uniform temperature. After gauging, pistons that fall within acceptable limits are automatically greased, wrapped in vellum paper, and packed ready for despatch.

It is stated that each of the two production-lines described above is operated by ten men, of whom seven are skilled. It is not stated how many men are required for the maintenance of this automatic factory during the third shift; nor what percentage of pistons are rejected.

EXAMPLE 2. A BUILDING-BOARD FACTORY IN THE U.K.*

(combining automatic process-control with bulk handling of materials)

The Bartrev factory of Vere Engineering Company at Marks Tey, Essex, shows how mechanical handling combined with automatic process-control can make a highly automatic factory. Its essential feature is the continuously working Bartrev press,

* This account is a free summary of an article by Rolt Hammond [127].

which replaces the usual static press. Figure 3 shows the general lay-out of the plant.

First, the raw material, wood, is ground mechanically to the required size. It may be partially ground already or it may be in large pieces, such as poles or logs. The chips are carried pneumatically to screening vibrators, which remove unwanted fines, and through a storage bin to a pneumatic drier.

The drier reduces the moisture-content of the wood to a specified and constant level. The level depends on the temperature of the chips as they leave the drier, which in turn depends on the exhaust-temperature of the drier. The moisture-content can be controlled, therefore, by control of the exhaust-temperature. Even when there are variations in the moisture-content of the material and in the rate at which it is fed, the exhaust-temperature can be kept constant by automatic control of the amount and temperature of air entering the drier.

The dried chips are fed to the press by a belt-conveyor, which acts in addition as a weighing machine. As they leave the conveyor they are sprayed with a mixture of resin and hardener solutions whose supply is controlled by two proportioning pumps which are so arranged that they can regulate the delivery of resin and hardener in separate streams, in any proportion, and at the desired rate of flow. The two streams are thoroughly mixed before being fed into the spraying apparatus.

The press combines four units; a feeding unit, high-frequency heating, the press itself and the automatic saws. The feeding unit lays a continuous carpet of sprayed wood on the lower of two bands of stainless-steel. The thickness and density of the carpet can be adjusted according to need. The pre-heating zone is formed by a battery of three radio-frequency heaters.

The press itself consists essentially of chains of radiant-heated platens and two steel bands, one above the other. The carpet is carried on the lower band, compressed against the upper band and heated, by transfer from the platens, to 110–150°C according to the type of board. The temperature is maintained by thermostatic control and the material leaves the press as fully cured and fully compressed board. The speed of the press can be varied to suit changes in the raw materials or in the resin-content, thickness or density of the board.

As the board emerges from the press, its edges are trimmed by two saws and it is cross-cut to the required length by a third saw, which travels on a moving carriage and which can be made to cut to any length by an adjustment of the trip-mechanism that operates it.

Thus, once the variables have been set so as to give the desired results, production is automatically controlled. If the variables are changed different types of board can be produced. The flexibility of the Bartrev press is one of its outstanding features.

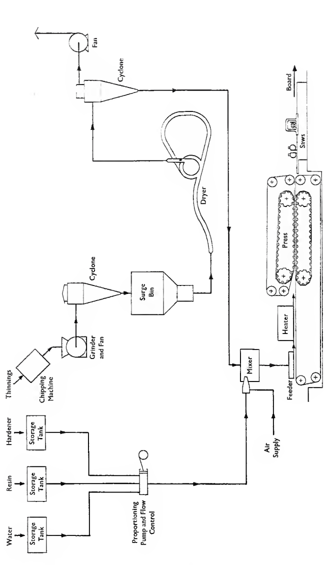
Water
Storage Tank
Resin
Storage Tank
Hardener
Storage Tank
Proportioning Pump and Flow Control
Air Supply
Thinnings
Chipping Machine
Grinder and Fan
Cyclone
Surge Bin
Dryer
Mixer
Feeder
Heater
Press
Saws
Board
Cyclone
Fan

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Figure 3. The Bartrev Process for the manufacture of building boards (U.K.)
(*a, above*) General view of the press
(*b, left*) Schematic diagram of the process

CHAPTER II

The Technical Trends

IT HAS been emphasized in Chapter I that recent progress with automation falls into three well-defined streams: the mechanization of manufacturing operations on components, of handling between processes, and of simple assemblies; automatic control of processes; and the use of electronic computers in automatic control and in the processing of information. The technical trends are now examined at greater length and in three sections, which correspond roughly with the three streams of development.

For the sake of convenience, however, the exact courses of these streams are not followed. No attempt is made to review all trends in mechanization in the small available space. One particularly interesting field, the machining of components, is chosen for a detailed account because it is compact, because recent developments have been striking and because a start has been made with the control of machine-tools by electronic methods. The many and varied forms of mechanization that have been introduced in other kinds of production, in handling, and in assembly, have been omitted.

A second change in coverage follows from this. Developments in the control of machine-tools by electronic computers are described in Section A, Automatic Machining, and not in Section C, Automatic Processing of Data, which is confined to the use of computers in offices.

A. AUTOMATIC MACHINING

The trend towards automatic machining of metals has been continuous and logical. It is based not on new principles of cutting but on more efficient techniques. Even the development of transfer-machines and the control of machine-tools by electronic methods are logical steps from the developments that preceded them.

The oldest form of automation in metal-working is the machine-tool that will perform limited functions automatically. Beginning with the engine-lathe, automatic machine-tools have been developed that will take raw material, whether it be bar-stock or casting, machine it, and deliver the finished product without human assistance. The screw-cutting lathe, invented by Henry Maudslay in 1800, was probably the first step. Out of it grew the modern precision-lathe, incorporating a variable speed drive from the headstock to the leadscrew and cross-slide; it turns, bores, faces, and threads metal parts under the control of a skilled machinist.

The shaping of each work-piece in the lathe calls for cutting tools of many different shapes. Each operation needs a change of tool and each change means re-setting the height and cutting angle of the tool, and that is skilled work. The turret was added to the lathe by R. S. Lawrence in 1854 so that semi-skilled workers could operate the machine. A battery of pre-set tools could be mounted in the turret and the appropriate tool for each operation could be indexed into position when required. Thus, a whole series of work-pieces could be completely machined by unskilled labour until the tools needed re-sharpening and had to be changed and reset.

The next step was the automatic lathe, invented by C. M. Spencer in 1870. In it the turret is automatically controlled, so that the slide-rest and the cross-slide of the lathe always move in proper sequence and the right cutting tool is always presented to the work-piece. Fed automatically by bar-stock, it will machine moderately complicated parts continuously until a tool becomes worn and one measurement falls outside the permissible limits.

TRANSFER-MACHINING

There is a limit to the number of tools that can be grouped round a single work-spindle, and in order to make one machine to do a greater number and variety of operations, it has been necessary to provide more spindles or devise more complicated machines. First a multi-spindle automatic machine-tool was invented for cutting small components; later came the transfer-machines for milling, drilling and tapping larger components (Figure 4). A typical application of the transfer-principle, in the machining of engine and gear-box castings for motor-vehicles, is outlined below.

EXAMPLE: MACHINING OF ENGINE AND GEAR-BOX CASTINGS

Though styles in motor-car bodies change almost as often as in women's clothes, the major components of the chassis vary much less in design. A new engine or gear-box will probably not become obsolete within five years. It is worth investing a considerable amount of capital in special-purpose machine-tools which enable these components to be made automatically with the smallest possible labour force.

Crankcase castings require more machining operations than any other components. Before transfer-machines were used, they first had their main joint faces milled and then moved on to a boring machine which finished housings for the main bearings. There followed drilling and tapping machines for the various studs, special jigs being used on standard machines. Often more than twenty machine-tools were involved before the casting passed to the fitting shop.

Nowadays all these operations can take place on the transfer-machine. The most specialized of these machines handle the casting without the help of a jig. The main location-face of each casting is milled on an individual machine. Then the casting is placed at the first station of the transfer-machine and is automatically clamped in a precisely located position, while the housings of the main bearings are bored and their sides are finished to size in the same operation. The boring bar withdraws, the chips are blown away by compressed air, the pneumatic clamps are released, and the casting automatically moves to the next position.

At this, the first drilling position, the casting is pneumatically clamped on its dowels. The drills advance with their guide-bushes, drill holes of the required depth, and withdraw. Air jets blow the swarf out of the holes, the clamps are released, and the casting moves on to the next position.

This may be another drilling position or a gauging position where the depth of blind holes can be measured automatically. If any hole is outside the accepted limits, the machine will prevent the casting from proceeding to the next station for tapping, because if there is insufficient clearance at the bottom of the hole the tool will break. The operator replaces the defective drill and either the crankcase is put through that station again, or the fault is rectified on a multi-purpose drilling machine (which is not part of the transfer-machine). When all the holes have been

drilled and tapped, the crankcase leaves the transfer-machine and is conveyed mechanically to the assembly-line. A very similar sequence is followed in making other large castings that cannot be accommodated on conventional automatic lathes with one or more spindles.

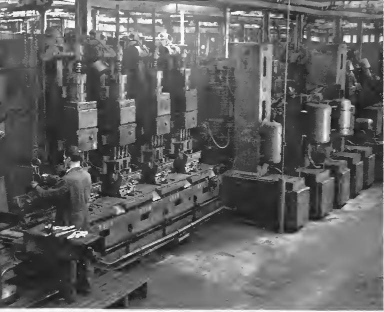
Transfer-machining has many possible applications. The first true transfer-machine was built in the Morris Motors factory at Coventry in 1924 and it produced cylinder-blocks from rough castings. Since then the principle has been widely applied to milling, drilling, tapping and broaching machines, especially in the motor-vehicle factories of the U.S.A., France and the United Kingdom. Automation of this kind is the result of co-operation between production engineers, designers of machine-tools, planning engineers, and experts on the handling of materials. The U.S.A. has tended to build very specialized transfer-machines, each of which is tailored to suit the product, and to scrap the complete machines when the design of the product is changed because of technical progress. British plants produce far fewer motor-vehicles in a year than the vast American plants and cannot write off the cost of transfer-machines so quickly. British production engineers have designed transfer-machines with standardized operating heads which can be easily shifted to suit changes in the design of the product. American experts seem to be moving in favour of these "unitized" machines, as they call them.

Transfer-machines can be used in the manufacture of any product for which a long production-run can be guaranteed. Any manual operation can be made fully automatic, provided that sufficient time, money and inventive genius are given to developing the necessary equipment; but if it is a very complex operation, automation may be uneconomic. Most assembly operations on the engines and chassis of motor-vehicles are still done by hand, though conveyors bring the parts to the assembler and pneumatic or electric nut-runners quicken the tightening of nuts and bolts. Some of the technically advanced factories are more automatic than others. The incentive towards automation varies according to the cost and availability of skilled labour.

PROFILE-MACHINING FROM A COPY

The tools used in transfer-machining produce simple forms like planes, cones, round holes and screw-threads in great quantities. They are the tools of the mass-production engineer. Another kind of machine-tool, the profiling machine, has been developed to make articles of irregular shape automatically. The search for it was stimulated by the demand for shaped wooden butts for rifles and in 1818 Thomas Blanchard, working at Springfield Arsenal, invented a copying lathe with a master-cam which transmitted motion to the slide rest through a proportional linkage. It made wooden butts efficiently but, when it was applied to steel components with complicated profiles, the master-cam quickly wore out under the high pressure needed to keep the follower against its surface. Even today there is no machine-tool that will make three-dimensional shapes rapidly from lumps of steel or other hard metal. Indeed, there is no call for it, because parts of complicated shape can usually be made in better ways, such as forging from billets, pressing from sheets, or casting in permanent moulds (die-casting).

These ways involve the use of dies; but the dies are wanted in small numbers and were once made by highly skilled workers using conventional milling machines. This was a slow process, until 1924, when J. C. Shaw invented an electrical sensing



Reproduced by permission of the Austin Motor Company, Longbridge, Birmingham

Figure 4. Transfer-machines
(*a, above*) For Austin cylinder-blocks (U.K.) (*b, below*) For Ford crankcases (U.S.A.)

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device which could operate by a very light contact with the master-cam form and which enabled the movement of the cutting tool to be controlled with the help of a servo-mechanism (or force-amplifier). J. W. Anderson followed with the all-hydraulic, tracer-controlled milling machine in 1927. Shaw's device was applied to the Keller die-sinking machine (made by Pratt & Whitney) and Anderson's to the Hydro-Tel machine made by the Cincinnati Milling Machine Company. These machines will produce accurate shapes in very hard die-steels from hand-made models of wood, plaster of Paris, or aluminium.

CONTROL OF MACHINE-TOOLS BY ELECTRONIC METHODS

The three-dimensional tracer-controlled machine for milling profiles was originally developed for die-sinking; but it was often used between the wars to make parts for experimental or prototype machines (which would be produced in a different manner if a production order was received). When making prototypes, this machine is guided by a wooden or plaster of Paris model, the making of which is often laborious. The whole operation would be simplified if the information contained on the drawing could be fed directly into the machine and the three-dimensional model could be dispensed with.

DIGITAL METHODS

At present engineering drawings are made for interpretation by craftsmen and not by machines. But the information does not have to be presented as a drawing. The shape of any three-dimensional component can be defined by the rectangular co-ordinates of its two-dimensional profiles in a multitude of parallel-plane sections, and the co-ordinates can be fed in an appropriate form to a die-sinking machine controlled by an electronic digital input. If sufficient co-ordinates are taken and fed in the right sequence, the tool can operate automatically. The programmer has thus to extract the necessary information about the movement of tools and feed it into the machine; he can do so conveniently with the help of a punched tape, like that used in teleprinters.

Automatic machines of this type have been produced first by the Massachusetts Institute of Technology, and later by Giddings and Lewis in the U.S.A. and by Ferranti in this country.(79) They will do anything that tracer-controlled die-sinkers can do, without using a model; but they are more complicated and expensive. Fortunately the extra cost can be widely spread; tape recordings can be copied as often as is necessary and one master-tape can serve very large numbers of machine-tools producing similar components.

The control of machine-tools by digital methods is theoretically far advanced. At least one small machine is on the market—a drilling machine in which the work is positioned in two dimensions by means of manually set switches. The General Electrical Company (U.S.A.) has developed a technique of control known as "record-playback", in which the behaviour of the machine under the control of a skilled operator is recorded on magnetic tape and is subsequently played back so as to provide automatic control without a human operator. The first unit of this kind is being used to produce self-reinforced skins for jet-propelled aircraft. Similar techniques are being developed by the firm, Alfred Herbert, in this country. The United States Arma Corporation has developed an automatic lathe to which information is fed in the form of punched paper-tape.

Figure 5. Control of a machine-tool by an electronic digital computer (U.K.)

(*a*) *Design*

The component is designed and dimensioned to suit the computer.

(*b*) *Planning*

The job is planned and the co-ordinates of each point of change, the type of curve, and the tool-feed and speeds are coded on punched tape.

(*c*) *Computer*

The computer reads the tape-input and produces continuous trains of pulses on four channels, inter-related so as to produce the required tool movement. These pulses are recorded on magnetic tape.

(*d*) *Machining*

Servo-mechanisms on the machine move slides to follow instructions from magnetic-tape distances being measured by optical gratings on each slide. Thus any three dimensional surface may be contoured.

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None of these machine-tools is likely to have a place in mass-production, except where parts of very complicated shape must be produced within limits of accuracy that are too fine to be achieved by direct forging and casting. Rotor and stator-blades for the hot ends of gas-turbines might be exceptions; thousands of them are required in peace time, possibly hundreds of thousands in time of war. If a magnetic-tape instruction could be prepared for such a blade—and this would not be an easy task—a hundred copies could be produced over-night and on the next day a hundred digitally controlled milling machines could be machining blade-profiles without skilled attention. Apart from a few exceptions of this kind, there is no need in mass-production for one universal machine which can make parts of any desired shape; the need is for groups of specialized machine-tools which will produce tens of thousands of identical components at minimum cost. Electronic digital control will probably be most widely applied in small-quantity production, in the manufacture of dies and master-cams, and in jig-boring.

So far as jigs are concerned, there is special interest in some recent results of co-operation between Ferranti and the National Physical Laboratory of the Department of Scientific and Industrial Research (Figure 5). The Light Division of the N.P.L. has perfected a method, devised by Sir Thomas Merton, for making diffraction-gratings in long strips at a comparatively low cost by cutting a very fine screw-thread on a cylinder and by making a plastic replica of the developed thread. A ten-inch length of grating, with 5000 lines to an inch, can be produced by this method for less than £5, and individual lengths can be joined to give any required total length while maintaining the correct optical phase-relationships. Two gratings can be arranged in a simple optical system so as to give 10 000 electrical impulses for every inch of relative movement between them. If the system is set up with one grating mounted on the sliding table of a milling machine and the other on the bed of the machine, it will be able to measure the distance that the table slides in ten-thousandths of an inch—a more accurate measurement than the normal lead-screw and nut can give. This technique will inevitably be applied to the measurement of table-movement on jig-borers. The next step is the direct electronic control of table-movement.

ANALOGUE METHODS

Machine-tools can also be controlled by an analogue computer, which differs from the digital computer in that it deals with physical quantities and not numbers. (Appendix I describes digital and analogue computers in more detail.) For instance, a length defined in an engineering drawing may be represented by a number of pulses in a digital computer but by a voltage in an analogue computer. A change in the input voltage will enable an analogue computer to move the cutting tool from one point to another in the same line of motion; and three applied voltages will completely determine the position of the cutting tool.

The development of an analogue machine of this type has awaited the perfection of a device which enables voltage-ratios to be manipulated with the accuracy required, which is about one part in 10 000. Such a device has recently been developed in Great Britain by Electrical and Musical Industries and has been applied to a machine for milling cams, which is controlled by means of a punched tape. All that is fed into this machine is a series of co-ordinates for the desired positions of the cam-cutter at a number of angular displacements of the work-piece. The analogue

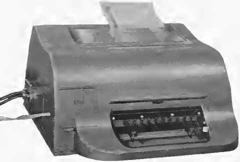
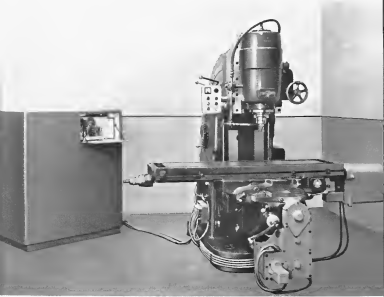


Figure 6. Control of a machine-tool by an electronic analogue computer (U.K.)



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computer determines the best curve through these points and guides the cutting tool along it.

An analogue-controlled universal milling machine is now being developed by E.M.I. in co-operation with the Cincinnati Milling Machine Company of the U.S.A. It will use a few electronic valves, but nothing like the number needed by digitally controlled machines.[73] (Figure 6).

B. AUTOMATIC PROCESS-CONTROL

The control of machine-tools by computers, as described in the foregoing pages, enables components of complicated shape, like dies, jigs and master-cams, to be machined automatically with great accuracy. Automatic control of one type or another is already widely established in the "process-industries", such as chemicals, petroleum, iron and steel, cement, paper, printing, food and brewing.

Automatic process-control is based on instruments that measure how far the physical or chemical state of a system varies from a desired value; and on the use of this information to restore the system to the desired state. There is no new principle in this. The steam-engine has had a governor since the days of James Watt and a patent was filed for the first pressure-cooker as long ago as 1680. The automatic pilot was flying aircraft in 1925 and before the last war automatic control was being developed in many industries, notably chemicals.

The process-industries have expanded very rapidly during the last 25 years, but many of them could not exist and none would have reached its present stage of development without automatic control. A good example is the silicone plant, the control room of which is shown in Figure 7. These industries are superficially unrelated, but the basic technical problems of control are similar in all of them and they resemble the problems that underlie, for example, the stabilization of ships, the control of guns, and automatic volume-control in a domestic radio-receiver. The operating conditions vary from one industry to another and each problem must be treated as individual, even though one instrument could be used to solve many different problems. Yet the aim is always the same: to maintain a specified quality in the final product while using the simplest and cheapest available equipment that will nullify the effects of random fluctuations occurring within the system.

Because the basic problems of control are similar, only one industry—the manufacture of chemicals—need be described in detail. A few examples are taken from other industries, but mainly because they are interesting; they are not necessarily representative.

CONTINUOUS PRODUCTION OF FLUIDS

Most factories with process-control consist of four basic units: the plant and the process, the measuring unit, the controlling unit and the correcting unit.[26]

The measuring unit detects and measures the value of controlled conditions (usually physical quantities) in a plant or process. The value of the temperature, to take one common variable, is transmitted to the controlling unit, which automatically compares it with the desired and pre-selected temperature. Whenever these values differ, a signal is sent to the correcting unit which alters an appropriate setting—of a steam-valve, perhaps—and brings the actual temperature back to the

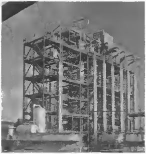

Figure 7. Control room of a silicone plant (U.K.)

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desired value. The plant itself forms an integral part of a closed loop (Figure 11) and must not be regarded as an independent unit to which instruments can be attached at will.

Although there are single closed-loop systems of this simple and general type, a plant more often has several systems, each of which helps to control a different condition in one process, such as temperature, moisture-content, pressure, level, or rate of flow. Where there is more than one process, more complex systems have to be used and they may include two or more basic units inter-linked in some way.

As future progress depends largely on developments in the four basic units, it is convenient to consider how each of them helps to solve technical problems of control.

THE MEASURING UNIT[53, 86, 93]

The quality of process-control depends on the accuracy, sensitivity and speed of response of the measuring units. These instruments must be reliable and—equally important—robust. In the early days of process-control engineers tended to install equipment of a laboratory type in factories and, not surprisingly, it failed to withstand the hazards of industrial life. Fragility is no longer a real problem and modern instruments are sometimes hermetically sealed and treated to help them resist chemical and biological attacks. They may be left unprotected for long periods in the most severe climates. They will measure with unimpaired accuracy in dusty or polluted atmospheres, or even when immersed in water for long periods. They can be made to operate continuously if required and to keep a record of changes in the measured values.

Instruments that measure the physical values in a system have been developed through several centuries and the accumulated knowledge, coupled with recent industrial experience, is being used in the design of modern units. They are now very satisfactory in performance and, while improvement will continue, it is no longer urgent. The immediate need is for equally good instruments that will make a continuous and rapid chemical analysis of materials while they are being processed. Only when they are available can automatic process-control be based on the measurement of the quality of the final product.

Instruments of this kind are already being developed, with notable help from techniques of infra-red spectrometry and mass-spectrometry. Oxygen and carbon-dioxide analysers are already being used in some controls, and continuous infra-red analysers have been installed in the process-stream of the new petro-chemical plant of the American Cyanamid Company (Figure 8).[82] The latter are infra-red spectrometers, which perform only one kind of analysis. They are built to withstand shocks and changes of temperatures. Moreover, they are extremely sensitive: one of them, for instance, is used to assess the amount of carbon dioxide that remains in one final product, acetylene, after it has been purified—the permitted proportion of carbon dioxide being roughly a few tenths of one per cent. The infra-red analyser notes the percentage of carbon dioxide continuously and plant-operators know immediately when to alter conditions in the plant so as to avoid either producing a sub-standard product or damaging equipment.

There is also a device which performs various routine chemical analyses.[166] Measuring units that utilise properties in the final product, such as viscosity, density and calorific value, may come into general use. They already have a place in the control of electric power stations, and are commonly used as indicators in the

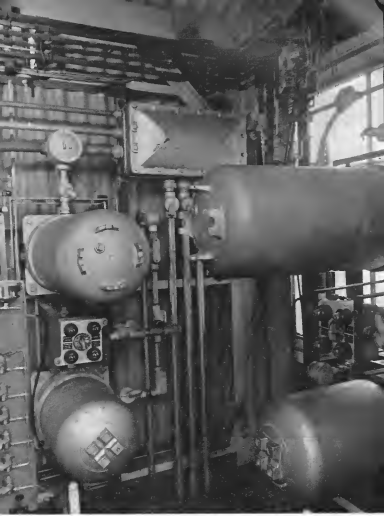

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Figure 8. Infra-red analysers monitoring a chemical process (U.S.A.)

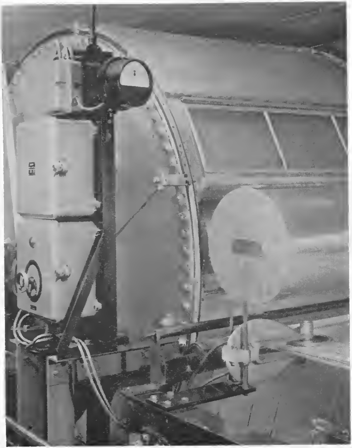

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Figure 9. Electrical method of controlling moisture-content in yarn-sizing (U.K.)

chemical industry, where their readings are translated into terms of the variable features in the processes.

In some industries, particularly the old-established industries, it is extremely difficult to develop measuring units. Manufacturers and customers often judge the quality of a product on what appears to be a purely subjective basis. The textile industries are a good example. It is possible to measure and control drafting and conditions like moisture content[97], the tension of threads during weaving, and the rate at which yarn and cloth are dried (Figure 9); but the relationship of these conditions to weaving properties and to the quality of the cloth as judged by feeling or draping ("handle" or "drape") is still insufficiently understood. In the food industry also, there are important subjective assessments—of taste and, to a smaller extent, perhaps, appearance and texture. It is hard to define properties like these, let alone measure them.

THE CONTROLLING UNIT

The controlling unit links the measuring unit with the correcting unit. When the measured condition in a process changes from a desired value, this unit automatically transmits a signal to the correcting unit, which takes appropriate action.

Controlling units can be made to operate in various ways, so as to deal with almost all possible problems. In "proportional control" the signal that determines the rate of corrective action can be directly proportional to the deviation of the measured condition. In "derivative control" the controller may anticipate deviations by taking account of trends in the condition, its operation being analagous to that of an aircraft gust alleviator. (This device measures air conditions at points several feet ahead of an aircraft and automatically adjusts the position of the aircraft control surfaces, whenever necessary, so that the aircraft is trimmed when it reaches the measuring point a fraction of a second later and the smoothest possible flight is ensured.) Other modes of control are possible, but a combination of two or more modes is usually desirable if the controller is to be as sensitive, and the process as stable, as possible.

The controlling unit can, of course, do more than maintain a particular condition at a roughly constant value. Designed in conjunction with other units in the control system, it can take a process through a prescribed cycle of conditions. It can, for example, heat the contents of a reaction vessel slowly at first and much more rapidly later (see page 30). Also the unit can be designed with enough precision to provide almost any operational characteristic that is needed, though it is very difficult to decide what that characteristic should be.

If controlling units are properly maintained they are extremely reliable but, should faults occur, they can give audible or visible warnings and the process can be automatically stopped unless alternative arrangements for its control have been made.

Modern controlling units may be operated mechanically, hydraulically, pneumatically or electrically. The pneumatic type is technically the most advanced and many reliable designs are available. It is thought that more than 90 per cent of the existing units are pneumatic. Hydraulic units are used mainly where oil systems are already installed, for instance in the oil-circulation systems of turbine equipment. It has become orthodox practice to install pneumatic or hydraulic controllers because they are simple, inexpensive and reliable and do not catch fire.

Electric and electronic units have not yet found much favour, although interest in their possibilities is growing. They can now satisfy the most stringent flame-proofing requirements; they have some advantages in performance, such as extremely high speeds of response; they are very convenient for use where signals have to be transmitted over long lines; they are more flexible than other types of controlling unit and so are particularly suited to the centralized control of a large plant. Also it is an easy matter to combine electrical units with mechanical or hydraulic units. But the choice between types of unit is based largely on simplicity, cost and reliability, and while this is so pneumatic units will undoubtedly remain in favour, except where an electrical unit is needed for special purposes.

THE CORRECTING UNIT

In the process-industries the correcting unit consists generally of two devices; a valve that controls flow and a mechanism that adjusts the valve in response to a signal from the controlling unit. In some cases, for instance an electric furnace or an electrolytic process, the unit may also contain a device that alters the electrical supply.

It is important to select a valve with the best characteristics; but this need be no barrier to progress, because the characteristics of the available valves are well known and it is technically possible to make valves with other characteristics to a given specification.

The air-operated valve is common in the process-industries, but hydraulically operated valves and dampers are also used, for example in the steel industry, where great forces are needed to operate them. The available air-operated valves cannot rival the hydraulically operated valves in speed of response, and this limits the efficiency of control in some modern processes. Also no electrically operated valve has been designed that is both quick in response and suitable for general use. But it is possible to combine the best features of hydraulic and electric systems by generating the control actions in an electrically operated unit and transmitting an electric signal to a hydraulically operated valve.

KNOWLEDGE OF PLANT-PROCESS SYSTEMS

It has already been pointed out that automatic control is often necessary to ensure that a product of specified quality is made in the most economical way. It is normally impossible for any "plant-process system" to operate in a steady state because of random variations in the characteristics of the plant (due to factors like the corrosion of components and changes in the characteristics of the catalyst); and because of variations in the quality of raw materials and in the supply of gas, electricity and steam. Automatic control must nullify the effects of these unpredictable disturbances if the final product is to be of stable quality.

Such a deliberate interference with the process always results in an interaction between the control equipment, the process and the plant, and so creates problems that can be solved only if the equipment is considered as a whole.[100] This interaction is described by the dynamic characteristics of the system, which are determined principally by the delay between the time at which a disturbance occurs and the time at which its effects are measured and corrected.

Unfortunately, although much is known about the dynamic characteristics of physical and chemical processes, there is very little basic information on the much

more complex behaviour of plant-process systems. Consequently automatic control in existing plants can be extended only by laborious and semi-empirical methods and it is not yet possible to design complex plant-process systems as single units. The full benefits of automation will not be obtained until much more research has been done into the dynamic characteristics of plant-process systems.

This gap in knowledge has a bearing on the control of operating conditions like pressures, temperatures and rates of flow. When a new plant is designed, conditions are specified that will give the desired quality and quantity of product. After a sufficiently long period of operation the actual conditions are generally found to be near the optimum, but both they and the optimum conditions are often very different from those that were specified at the outset. In fact, the specifications have been modified by trial and error, with contributions from expert knowledge of the process and from accidental discoveries. If control of the process is adequate, the number of experimental runs can be much reduced, but even so, they are time-consuming and laborious in a full-size plant and that explains much of the inevitable delay between the construction of a new plant and the attainment of its greatest possible output. When basic information is available on the characteristics of process and plant, the behaviour of a plant-process system can be simulated with the help of an analogue computer (see Appendix I); and the optimum operating conditions of a new system can be determined cheaply and rapidly without trial and error on a large scale.

A simulator of this type has been developed and built at the National Physical Laboratory of the Department of Scientific and Industrial Research and is now available for the solution of problems submitted by industrial and other organizations (Figure 10). It can be used to study linear systems of a high order and complexity, including pure time-delay. Simple non-linear problems can also be studied, and the equipment is being enlarged so as to extend its scope in this direction. The accuracy of any setting is of the order of 1 per cent, and this is adequate for the solution of most problems of process-control. A charge is made for work carried out on the simulator and is based on the cost of staff and overheads.

Already an electronic digital computer (see Appendix I) has been used in the petroleum industry to predict the relationships between operating conditions and the quantity and quality of the product in some important processes.[95] This statistical approach, based on the behaviour of the plant in different sets of conditions, appreciably reduces the amount of trial and error, but it still requires facilities for large-scale experiments and it contributes little towards the solution of the basic problems.[114]

BATCH PROCESSES

In batch production automatic control is usually over heat-transfer processes, in which the contents of reaction-vessels are often heated or cooled by means of internal coils, or electrodes, or by wall-heating elements. The volume of the reactants is usually large and they must be well mixed or the measuring units cannot obtain accurate information about conditions at remote distances from the measuring heads.

Further difficulties result from changes in the physical properties, like density and conductivity, and in the process-conditions of the reactants, like pressure and temperature. A wide range of conditions and properties has to be measured and because of this, it is usually impossible to provide a comprehensive system of instrumentation and control. Finally there are difficulties in measuring the properties of the final product continuously (see page 24). They generally confine measurement

and control to variables like temperature, pressure, electrical conductivity and perhaps vapour-pressure.

A reaction-vessel is usually charged semi-automatically. Before raw materials enter it, they may be weighed automatically on a feed-conveyor if they are solid, or measured by flow-meters if they are liquid.[169] Alternatively liquid-level controllers can be installed within the reaction vessels. After the charging, the reaction usually follows a closed cycle of operations which has been found to provide an optimum yield. For instance, the contents of the vessel may have to be heated rapidly to a particular temperature, and held at that temperature for a given time, before being cooled and discharged.

A product of uniform quality and highest yield is obtained only if the process-conditions are accurately controlled and exactly reproduced for every batch. This means that the cycle of operations must be planned and controlled on a definite time-scale. Control of this type can be applied either manually or automatically. Automatic control often involves the use of mechanical programme controllers—possibly a set of cams driven by an electric motor—which enable variables in the process to be automatically changed and controlled at any chosen time in the closed cycle of operations. A programme-controller can also be used to operate valves that automatically discharge the product at the end of the process.

The iron and steel industry and other metallurgical industries use batch processes on a vast scale. All metals pass through furnaces at least once, often four or five times, before they reach their final forms, and on each occasion they undergo a batch process. Much fundamental and applied research is being done to discover exactly what happens in a furnace.[145] The results are being applied by the user-industries and some of them contribute to the design of more comprehensive systems of furnace-control.

To cite one example, it is now generally accepted that an optimum yield can be obtained from an open-hearth furnace only by controlling the temperature of the roof. If the temperature exceeds a certain level, the refractory roof-lining burns away rapidly, the furnace has to be closed down for renovation more often than is necessary, and there is an avoidable loss of production. In steel furnaces, which are extremely hot, temperatures have to be measured indirectly by optical or photo-cell pyrometers. The roof-temperatures of glass furnaces are very much lower and temperatures can be measured directly by platinum thermo-couples, sheathed with refractory material and built into roofs. The measurements are used to control the input of fuel so as to maintain the roof temperature at the desired level. Control of this kind is widely used in all types of furnaces.

There are countless batch processes of a different type, and on a smaller scale, in the other process-industries: but the problems of control are similar to many of those of the engineering industry. For example, accurate control of position is as vital in colour-printing as it is in machining, and it is needed on the individual tools and machines that are used for wrapping, packing, filling, printing and cutting.[80]

CONTINUOUS PRODUCTION OF SOLID SHAPES

This covers the manufacture of products like wire, paper and fibres, in which automatic control usually involves the measurement and control of the physical conditions of the product, such as dimensions, speed, tension and moisture-content.

Control of dimensions is probably the most important aspect, as the efficiency and cost of the manufacturing operations that follow it depend very much on how

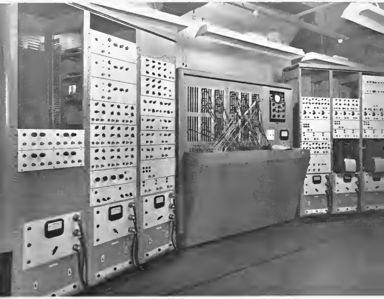


Figure 10. Electronic simulator at the National Physical Laboratory (U.K.)

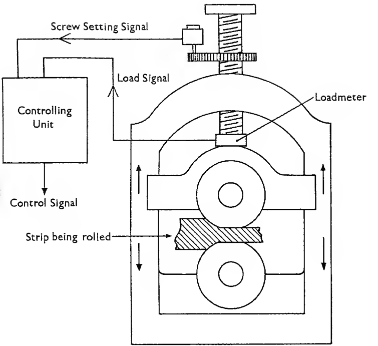


Figure 11. Continuous control of thickness in rolling mills
Method devised by the British Iron and Steel Research Association

accurately it can be done. For example, if steel strip or sheet exceeds the permitted dimensional limits when fed to machine-tools, the tools break and the machines stop frequently, causing serious losses of production.

Similar detrimental effects can occur in operations as diverse as pressing, impact-extrusion, and electrolytic finishing. Indeed, but for precise control of dimensions, many existing operations in mass-production would be impossible.

During the production of sheet materials of all kinds it is often essential to measure the finished thickness continuously and keep it within close limits or tolerances. The continuous measurement of variations in the thickness of a strip often calls for a measuring gauge of the non-contact type. For instance, the strip may move so quickly (steel strip at over 4000 feet a minute and paper strip at 1400 feet a minute) that a contact gauge would vibrate excessively and would give spurious results. In other cases the surface of the strip may be soft and tacky, or possibly too weak to support even the lightest mechanical-contact gauge.[175] The thickness of a coating on a base-material, such as the thickness of tin on tin-plate, can be measured by a radio-active thickness-gauge,[101, 105] though it is possible to develop suitable devices based on the measurement of electrical resistance or on the transmission and reflection of ultrasonic waves.

An unusual and interesting system of gauge-control is being developed by the British Iron and Steel Research Association for use in steel rolling mills (Figure 11).[90] It has been shown that the force exerted on the rolls by the contact of the steel strip is a measure of the "exit gauge" of the strip. To measure it a load-meter is placed under the mill-screws that are used to load the rolls. The meter gives an electrical signal which, after amplification, can be used to control the speed of the motor that drives the strip-coiler. A rise in speed increases the tension in the strip and so reduces its thickness. This method cannot be used in hot rolling or when very large tensions have to be dealt with; but an extension of the method makes it possible to exercise control by changing the settings of the mill screws; and this new technique can be applied to hot or cold rolling. Serious difficulties are created by the wear and deformation of mill-components, the slow methods used to load the rolls, and other factors; but in spite of them this method gives control of a very much better quality than that given by earlier techniques.

CONTROL OF COMBUSTION

The Report of the Committee on Air Pollution[132] drew attention in 1954 to the serious damage and wastage, costing about £250 million a year, that is caused by excessive smoke from industrial and domestic chimneys. The basic cause of the smoke, incomplete combustion of fuel, wastes ten million tons of coal a year and so costs the nation an additional £25–£50 million.

It is thought that about 50 per cent of atmospheric smoke is due to domestic fires. Little can be done about it beyond providing—and encouraging people to make more use of—smokeless fuels, improved heating appliances, and space-heating systems. But there is no need for industrial equipment to emit more than traces of smoke and the amount that it does emit can be reduced by legislation. Some "smokeless zones" have already been established in this country and abroad and the Clean Air Bill has focussed attention on the possibility of extending them in Great Britain. As a result there is considerable interest in the control of combustion.[140]

In a power house it is sometimes difficult for the stoker to see how much smoke he is making. However the decline in the intensity of a beam of light, after it has

traversed the flue-gases in a chimney-stack, is a practical measure of the density of smoke. It can be measured by a photo-cell in terms of an electrical signal, which, after amplification, can set off an alarm whenever the density of smoke exceeds a specified amount (40 per cent absorption of light, according to a recommendation of the Committee on Air Pollution).

Small industrial boilers are normally fitted with as few instruments as possible and even they are often in a bad condition through lack of maintenance.[139] However, inexpensive semi-automatic systems, which control the consumption of fuel and minimize the emission of smoke, are being more widely used.

For example, small Lancashire boilers can be fitted with special smoke-eliminating doors, originally designed by the Fuel Research Station of the Department of Scientific and Industrial Research.[133] These doors regulate the supply of air to the boiler between successive stoking operations and so ensure a high thermal efficiency in the boiler. They increase the thermal efficiency by 7 per cent in many cases and save a hundred-weight of coal for each ton burnt. But the control they give is not sufficiently precise to overcome variations in the quality of the fuel or in the thickness of the fuel-bed on the boiler grate. To overcome this difficulty, a photo-electric alarm (described above) informs the stoker when he needs to admit more air to the boiler in order to ensure that fuel is completely consumed and smoke eliminated. That is why systems of this type are described as semi-automatic.

In large power stations and other units that consume enormous quantities of coal each year the thermal efficiencies of boilers must be as high as possible. It is necessary to have completely automatic systems of combustion-control which secure the maximum amount of heat from the coal that is consumed (Figure 12). These systems are much more elaborate than the smoke-indicator system described above. The flow of air into the furnace is measured, as well as the flow of gases through the various parts of the furnace. Other relevant factors, such as the input of fuel, the supply of water to the boiler, and the output of heat in terms of the flow of steam, are also measured and controlled in order to build up a complete picture of how the plant is operating and to obtain the best possible performance from it.

SMALL FIRMS

The process-industries are dominated by many large firms producing vast quantities of materials to amazingly uniform specifications; but smaller firms do exist and, unlike the larger firms, their livelihood does not necessarily depend on using automatic control on an ever-increasing scale. Their problems are essentially different from those of the large firms. They often produce specialized products in small quantities. They may frequently have to change their products to meet the individual requirements of customers. Indeed, many of the smaller units continue to exist merely because they are highly flexible.

Automatic control devices are often built into the machines used by small firms, and occasionally they are applied to machines that may have been operated by hand for several decades. Economic considerations are often decisive and sometimes they can be assessed fairly accurately.

Two hypothetical examples are given here to illustrate the possible advantages of automation to small firms. In the first an imaginary firm produces a fabric coated with polyvinyl chloride (P.V.C.) in small quantities, say 2000 yards a day. It probably possesses one or two small machines for spreading. The coating process is essentially small in scale, low in speed and continuous in operation and seems to be

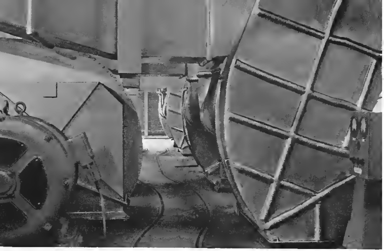
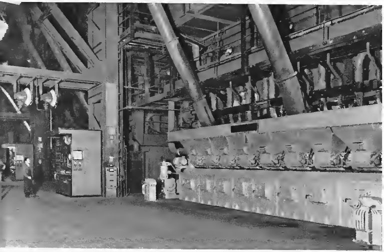


Figure 12. Automatic control in power-stations (U.K.)
(*a*, *above*) Boiler-firing aisle, showing control equipment (Staythorpe)
(*b*, *below*) Forced-draught fan (Deptford)



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suitable for automation; but in practice it is probably operated by hand. An operative pours P.V.C. paste on to the fabric base, perhaps four feet wide, as it is unwound from a large reel. The fabric passes through a pair of calender rollers, which spread the P.V.C. paste uniformly over the fabric. Then it is cured, reeled and despatched. The final thickness of the P.V.C. coating is determined by the separation of the calender rollers. The thickness must be uniform to ensure a product of high quality and to avoid wastage.

Control of thickness is extremely important, particularly as the other variable conditions in the process—the speed at which the fabric moves and the gradient of temperature in the curing oven—are not critical in any single production-run and there can be satisfactory performance if their values are determined and pre-set on the basis of previous experience. When the separation of the calender rollers is controlled by hand, it is pre-set for every production-run on the assumption that the pre-set values will not change significantly during the run. The arrangement works reasonably well and can be expected to give a variation of 3–4 per cent in thickness where the coat is fifteen-thousandths of an inch thick. Even so, automatic control of separation would improve performance.

The technical problem of control is not easy, however. The process has almost certainly to be operated at low speeds—between one and five yards a minute. The thickness of the P.V.C. coating must be measured before it enters the oven—indeed as close to the calenders as possible—if control is to be of a high quality. The measuring head must be of the non-contact type (see page 33), as the "tacky" surface cannot be disturbed. It must also be sensitive enough to detect minute variations in a total thickness which does not exceed two or three hundredths of an inch.

There are two obvious methods of dealing with this problem. A radio-active thickness gauge of the scanning type[104, 105] can measure the thickness of the P.V.C. comprehensively enough to operate an appropriate controller successfully. Models are on sale, and are readily available, which reduce the variations in thickness from 3–4 per cent to 2–3 per cent, but this may not be sufficient to offset the capital and maintenance costs of a control system.

Alternatively a system using pneumatic gauges could be devised, but none is yet available commercially and small firms are normally unable to develop one even if they are convinced that this single application is worth the effort involved.

The second hypothetical example concerns a farmer or market gardener who wants to market his own seeds but must sort them beforehand. Sorting is laborious and expensive when done by hand, but there is an electronic machine which will do the job quickly and cheaply, using a colour-selection principle. Machines of this type already screen peas and beans before canning, and it might prove economic for a small grower to install one or hire one for short periods.

THE PRESENT AND THE FUTURE

The importance of automatic control systems is now established. Indeed the control equipment installed in a new chemical plant or petroleum refinery may represent as much as 20 per cent of the entire capital equipment in terms of cost, compared with a very tiny fraction 25 years ago.

The quality of final products in the process-industries is currently checked by laboratory tests on samples taken at various points in each process; and it is maintained by an adjustment of conditions in the plant according to the results of these tests.

In many units a great number of variables control the process and plant, and time-consuming calculations are needed to assess the effects of deliberate changes in the operating conditions, in raw materials and in plant characteristics, before it is established whether the unit is running at the optimum level. The calculations can be done readily on an electronic computer, and in future it should be possible to integrate them with the direct control of all variables in the process and plant. To make best use of the high speed at which a computer works, there must be a negligible time-lag in transmitting signals to it. This implies that electrical systems of transmission will be used and that measuring units that give an electrical signal direct will be better than those that need a mechanical, pneumatic or hydraulic-electrical converter.

If the present trend is followed, much process-control of the future will be based on the measurement of quality in the final product, though not until techniques of instrumentation are much farther advanced.

Very little is known about the dynamic characteristics of plant-process systems. They vary from one system to another and wherever there is new equipment the behaviour of plant and process must be worked out laboriously, and on a large scale, by costly and empirical methods. But it is thought that, with the growing use of analogue computers, it will soon be possible to make quantitative designs of realistic control systems for new installations.

The underlying unity of the basic principles of automatic control is gaining general appreciation. The speed with which these principles are applied to the process-industries depends in the main on how closely chemical and control engineers can co-operate with each other and learn the essentials of both techniques.

C. AUTOMATIC PROCESSING OF DATA

The use of electronic computers is still at an early stage in the control of machine-tools and in the process-industries; but it is slightly more advanced in business operations and routine clerical work, and it forms part of an important trend towards automatic operation in the office.

The forerunner of modern mechanical office equipment was the adding machine, invented by Blaise Pascal in 1642 but not produced commercially until 1873. The machine saved time and eliminated arithmetical errors; but mistakes could still be made when feeding figures to the machine or when recording results. In the twentieth century specialized adding machines have been evolved to fit different account-needs. The cash-register, for instance, records individual sales and the cash they bring in. Many specialized book-keeping machines have been produced and punched-card systems were first used on machines of this type, though they have since been put to many other purposes.

Punched-card systems are undoubtedly the half-way stage between old-fashioned clerical work and modern electronic computers. Information is punched on individual cards and is mechanically arranged, tabulated and printed in any desired manner and more cheaply and quickly than by previous methods. Punched cards were the first office records on which the information was not immediately apparent. This limitation has been generally accepted and a similar limitation may be acceptable in the case of computers. Many functions of existing punched-card devices are performed by computers, but not all of them; sometimes the two types of equipment are used together.

Electronic business machines meet two basic needs: they obtain more information more rapidly and so make business operations more efficient; and they mechanize clerical work at a time when it is becoming increasingly complex and the numbers and wages of clerical staff are rising.

ELECTRONIC DIGITAL COMPUTERS

The term "electronic digital computer" covers many devices doing a variety of work (see Appendix I). There are two main types: those that mainly calculate and those that mainly memorize or store data. The former type is really a machine for solving scientific and technical problems, like those of nuclear physics or engineering design. It does heavy mathematical work which often cannot be attempted by the old methods. It receives few data at a time but does a large amount of computation with them. Computers of this type have only recently been introduced to industrial problems—initially to routine clerical work. For example, the National Physical Laboratory of the Department of Scientific and Industrial Research has been studying the possibilities of using them in wage and salary accounting. It has worked in consultation with the Ministry of Pensions and National Insurance and the Organization and Methods Division of the Treasury. It is about to publish a report.

The other type of computer, which mainly stores data, already has many possible applications in commerce. It usually does very simple arithmetical work and its calculating section is very small. But its storage capacity must be very large and the stored information must be easily accessible.

Before a large digital computer can be used in an office, existing procedures must be linked with computer programmes. Most office procedures have grown haphazardly and are not yet known in complete detail. This defect must be remedied before staff is trained to "programme" the flow of work (that is to say, to reduce each problem into a number of simple and separate problems, all of which a computer can solve); and this study may take several years in a large organization since it involves a detailed analysis of existing clerical and accounting procedures. So far this time-lag has softened the impact of large computers on existing office staffs. But, as experience grows, some accounting procedures will be standardized and will become ready-made routines for computers, which business houses can adopt immediately. The time-lag will be reduced, though probably not eliminated.

The detailed thought that must precede an installation of a computer often confers benefits that have not been thought possible hitherto. For instance, when the General Electric Company (USA) was developing techniques for defining its "line-balancing" programme, its production staff was able to save 100 000 dollars a year in one department before the computer, a Univac, was installed.(117) Benefits like this are solely due to a better understanding of working operations.

The use of computers, by reducing clerical staffs, makes financial savings which are often considerable and are immediately apparent once the programme for a particular project has been worked out. But it has other advantages which are not apparent and which cannot be assessed easily in terms of money. For instance, up-to-date facts and figures will replace the incomplete figures and guesswork on which company executives of today must base their policies. Information of this kind is valuable to large firms and may prove no less valuable to smaller firms.

SINGLE-PURPOSE MACHINES

Small computers of this type were the first to be used in offices. The problems they were given could be specifically defined at the outset.

A typical machine is the Remington Rand seat-reservation unit which was recently installed for the benefit of airlines using La Guardia airport, New York, and which does the work of several hundred clerks. Previously, an inventory of available space on aircraft was posted on a board and more than 2000 plaques were used to indicate vacancies. Now, an inventory for ten days ahead is kept on two magnetic drums, rotating more than 1000 times a minute. Ticket agents question the computer in their own offices by means of press-button units which are linked to the machine by direct lines. The answer returns in the same manner and is indicated by a code of lights. Cancellations can be made just as easily as reservations.

A similar magnetic-drum system is used by a large mail-order firm in the U.S.A.[115] With its aid, ten order clerks can provide accurate and up-to-date tallies of 12 000 different items at any time of the day and can deal with about 80 000 orders daily. The machine was installed because the clerks could not keep their work up to date at rush periods and made frequent errors, causing the firm to lose business.

GENERAL-PURPOSE MACHINES

Large companies tend at present to install multi-purpose computers which can accomplish all these special tasks without undue difficulty and can do others as well.

In the United Kingdom several firms, including the British Tabulating Machine Company, Powers-Samas Accounting Machines, Elliott Bros. (London), the Plessey Company and IBM United Kingdom, are producing small electronic computers. Some of these machines are not really computers but calculating machines. They are very suitable for use in conjunction with existing equipment, such as punched-card records, sorters and collaters. To take one example, a Powers-Samas electronic multiplying punch was installed by British Railways at Crewe in January 1955[187] and is used for problems of documentation and for control of stock. Each calculation is done separately by two different electronic circuits and only if the answers are identical are the results printed for action.

In the U.S.A.,[179] the International Business Machines Corporation and Remington Rand already produce large digital computers that are specifically designed for clerical operations—the IBM 702 and 705 and the modified Univac. Remington Rand has installed fifteen Univac machines in the U.S.A. and more are on order. Eight of the existing installations are in Federal Government agencies while seven are hired to business and industrial firms, among them the General Electric Company (U.S.A.), Sylvania Electrical Products, the Metropolitan Life Insurance Company, the Franklin Life Insurance Company, the United States Steel Corporation (two installations) and the Chesapeake and Ohio Railway. Eighteen large IBM machines have been installed by industrial users, such as the Chrysler Corporation, the Ford Motor Company and the Monsanto Chemical Company. It is reported that a hundred more machines have been ordered.

FIVE RECENT APPLICATIONS

GENERAL ELECTRIC COMPANY (U.S.A.)[115, 117]

Five separate departments of the Electrical Appliance Division of the General Electric Company are concentrated in Louisville, Kentucky, and a sixth is situated nearby. Until recently all these departments were dispersed, and it was agreed that they should be centralized because of potential savings in overheads, freight charges and other costs. This was impossible without precise central control, which in turn

required a computer. A Univac machine was installed before a large central clerical staff was built up. It was considered that the capital cost of the machine would be economically justified if it worked for at least two hours a day. Four initial applications have made this amount of work possible:

Pay-roll: A complete and integrated pay-roll system for all employees (10 000-12 000) is now in operation.

Scheduling of materials and control of inventories: The computer digests the mass of source-documents that affect statistics of inventories and issues reports based on daily analyses of conditions. It can analyse any proposed schedule of production and automatically determine how much of each material is required over any period. It may eventually write purchase orders, telling the management what to buy, in what quantities and from what supplier; also schedules, telling suppliers the date on which the materials must arrive at the appliance division.

Service and billing of orders: This involves the mechanization of routine clerical work. It is planned that the computer will process orders received from distributors, and will prepare letters of acknowledgement, invoices, shipping-release schedules and other documents. It may be able to prepare consolidated schedules for despatching goods to dealers.

General and cost accounting: The information obtained by the first three applications will be used for the preparation of the usual financial reports and statements.

Eventually, it is hoped, the computer will be able to provide factory machine-loading schedules in "real time", and will deal effectively with problems of budgeting, marketing and balancing assembly-lines. The ultimate objective of the company is to develop an integrated system of control which will produce sales analyses quickly enough to match changes in the sales of various appliances, and so help the management to modify production accordingly.

J. LYONS AND COMPANY (U.K.)[182]

J. Lyons and Company began to investigate the possibility of designing computers for office work in 1947. A prototype based upon the Cambridge University machine, EDSAC, was in operation by 1951 but only in 1953 was there a reliable machine with fast input-output systems which could be turned effectively to clerical procedures. The computer, called LEO after the initials of its full name, "Lyons' Electronic Office", was set to work immediately and in January 1954 it prepared the pay-roll for one department of 1700 employees. With further experience LEO proved itself very reliable and was given more work to do. It now calculates the pay-roll for 10 000 employees in about four hours instead of thirty-seven full-time clerks under supervision using orthodox office machinery (Figure 13). Towards the end of 1955, it began to work out the pay-roll for the employees of an additional large company.

LEO also handles the daily orders to the bakeries from more than 150 Lyons teashops. Every afternoon it prepares all the data and records relating to production, assembly, packing, despatch, cost accounting and other processes. Final revisions are received by telephone before 3.30 p.m. and the job is completed by 4.45 p.m.

After accomplishing all these tasks, LEO still has time for a variety of contract work for outside companies.

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Figure 13. LEO, Lyons' Electronic Office (U.K.)

The amount that LEO can save in clerical costs depends largely on the nature of its work but, according to one estimate, it could easily be £100 000 a year and might be considerably more. A new machine, LEO II, has recently been designed: it can work four times as fast as LEO I and should be even more reliable. Its capital cost will be about £75 000.

MONSANTO CHEMICAL COMPANY (U.S.A.)[178]

This company has installed an IBM 702 machine mainly to discover how to apportion overhead charges when calculating the cost of any chemical product. In factories that supply many different products, and particularly in chemical works and petroleum refineries, the distribution of total costs is very complicated. Even in simpler industries it is often so obscure that factory managers have difficulty in discovering the actual cost of a product quickly enough to give the information significance.

Before a single cost-sheet could be prepared for one Monsanto product, a large set of simultaneous equations, the equivalent of 400 000 arithmetical operations, had to be solved; and it took nine months to devise the full programming instructions. The programme is now fixed more or less permanently, and will remain so unless the planning procedure is changed. At present the computer produces 1200 cost sheets for individual items and also undertakes quarterly financial reports and other accounting jobs, which are normally done with the help of standard calculating machines.

INSURANCE COMPANIES (U.S.A)

The Franklin Life Insurance Company adopted the Univac system in 1952[180] and uses it extensively for premium-billing, policy loans and dividend payments. So far it has spent over 150 000 dollars on training programmers, engineers and technicians, on preparing programmes, on spare parts and on other items. Operating costs, excluding the cost of programming, will amount to about 150 000 dollars a year; but it is estimated that at least 200 employees, and salaries totalling about 425 000 dollars a year, will be saved when all the operations now being considered are converted to the Univac system. In addition about 80 000 dollars a year will be saved on rentals of existing accounting equipment. The company believes that it can recoup the cost of the Univac system in less than four years.

The Prudential Assurance Company is using smaller computers for actuarial problems, premium billings, the preparation of dividend cheques and other tasks.

BANK OF AMERICA (U.S.A.)[183]

Many people associate the idea of an automatic office almost exclusively with the electronic digital computer, but there is another important innovation, the electro-mechanical book-keeping machine, which is colloquially named ERMA (meaning "electronic recording machine accounting") and which has been developed by the Stanford Research Institute for the Bank of America. The prototype model will do all the book-keeping for 32 000 current accounts, but the management of the bank expects that 57 machines will be needed to serve its branches throughout California.

All cheques drawn on an account bear its number, as do all the relevant deposit slips. The number is printed in code with magnetic ink and can be read by the magnetic pick-up head of the machine, the method being analogous to that of an

ordinary tape-recorder. Bundles of cheques and deposit slips reach ERMA'S operator in the usual way. Before feeding a cheque to the machine the operator informs it that the item is a cheque for a particular amount, and not a deposit. The machine identifies the number of the account and extracts relevant information concerning the state of the account from a memory unit of the magnetic-drum type. This information, together with that which the operator has already supplied, is passed to a simple calculating unit which determines the new current balance or over-draft. The result is transferred to the temporary drum-storage unit and later to an appropriate position on a bigger magnetic-tape storage-unit. Every month the information on the tape is printed automatically as a conventional "account statement". A second independent magnetic reader and sorter is used to sort and file cheques and deposit slips by account numbers when ERMA has finished with them. They are combined with the monthly statements before despatch.

Several specialized problems have had to be solved during the development of ERMA. For example, it can now fairly accurately identify printed arabic numerals, as well as coded numerals and letters, even when they are almost obliterated by ink or over-printing. New, accurate and reliable methods have been devised for handling cheques of various sizes and weights. Experience like this will make it easier to solve the very difficult yet important problems that arise in the handling of "raw data", and are common to all data-processing operations.

TECHNICAL LIMITATIONS OF EXISTING COMPUTERS

SPEED

The fast operating speed of computers is wasted unless it can be used to the full and much can still be done to quicken the rates at which data are put in and out of the machines.

One of the promising developments under investigation is the zerographic printer recently developed by the Haloid Corporation in the U.S.A. It will print 108 000 characters a minute. A second development, the magnetic reader, which has been developed for the new book-keeping machine, ERMA (see above), could easily be incorporated in the input sections of electronic computers and could enable computers to use "raw data" directly. Another device, called FOSDIC (meaning "film optical sensing device for input to computers"), has been developed by the National Bureau of Standards in the U.S.A.; it will read marks made by an ordinary pencil or pen on micro-film copies of documents, then process the information automatically into electrical pulses, record them on magnetic tape and feed them into a computer. This completely automatic machine has been used to translate the information on the record-schedules of census-enumerators into a form that can be accepted directly by a computer. These machines and their successors will do much to ensure that the high speed of computers is eventually used to the full.

RELIABILITY AND ACCURACY

It is essential that electronic machines for offices should be as reliable and accurate as possible, and the results obtained by present-day computers are much better than those achieved by manual methods and are thought to be adequate for every practical job. This is one reason why the use of computers is spreading. Standard calculations are available which can be used to check the accuracy of performance. In a few cases it is arranged for each calculation to be made twice by independent parts of the

computer and only if the results are identical does the calculation proceed further.

Most computers are built on the unit-principle so that a faulty unit, once identified, can be replaced in a few seconds. But faults can normally be avoided by the daily use of a marginal checking procedure, which enables potentially faulty components to be identified and replaced before they fail in service. Valve-failure has been reduced in importance by the use of high-quality valves and by the introduction of long-lived crystal valves,[181] and it is now one of the minor causes of unreliability in computers. In fact, they are least reliable nowadays in the input-output stages, where mechanical devices are still used. It is not easy to forecast the effects of wear or the occurrence of breaks in the tape and it is impossible to eliminate them by preventive maintenance.

The reliability of present-day computers can best be illustrated by a few examples. First, practical experience with the computer LEO over a number of years (see page 40) has shown that it can do clerical work reliably and more accurately than conventional methods to daily, and even hourly schedules. Faults that occur during operation have been reduced to two or three a week and most of them take only a few minutes to rectify; only three took more than an hour during the first half of 1955. Secondly, it is claimed that the machine used for the automatic reservation of seats at La Guardia airport (see page 39) is idle on account of faults for an average of only 0·2 per cent of a working day of 22 hours; but there are additional stoppages owing to failures in the input-output systems.[185] The machine is as reliable as this because it includes two identical calculating and storage units in a basic-unit construction. Thirdly, the Univac scientific computer (ERA – 1103) has operated for more than 43 hours without error during acceptance tests held in connection with one new installation.[185] The only stoppages were due to the clogging of punches with paper-tape. Lastly, it is stated that an IBM 650 machine operates consistently without attention over whole weekends.[185]

THE FUTURE

Less than ten years after the completion of the first electronic digital computer in the U.S.A., all the main manufacturers of business-accounting machinery in the United Kingdom, the U.S.A. and France are entering the field. It can be assumed that there is much scope for computers in offices.

The use of computers will call for a careful re-examination of office routines that are acceptable today, and it will probably change them in many ways. But computers will almost certainly be introduced gradually. They will often replace clerical staff, but they will also produce data that either could not be produced before, owing to the limitations of the existing equipment, or took so long to produce that they were virtually useless when they became available.

It is thought that small firms, as well as large firms, will benefit from the use of computers. They will probably not buy equipment outright but will employ hire-service arrangements which manufacturers of computers are now making in several parts of the country. Arrangements of this kind may be adequate for some years.

Existing computers are sufficiently reliable for all accounting purposes. Computers are available in various price ranges, the expensive models being more powerful than the cheaper ones. There are indications that specialized machines may be a handicap in this rapidly developing field, as users must always work within the limits of the equipment. Large digital computers, being flexible and versatile, are not restricted in scope and they offer the most rapid means of achieving a fully automatic office.

CHAPTER III

The Extent and Rate of Development

THE TECHNICAL developments described in Chapter II must have a considerable impact on industry in the future, but their extent and rate will be governed by a variety of economic and social factors, the most important of which are reviewed in this chapter. Most of the problems are not new, but are common to all technical changes in which labour is replaced by plant; and they have probably been experienced by any firm that has accepted the need for continual technical innovation. There is, however, one new element in technical change—high speed of development. In the past, innovations have been established slowly. The initial mechanization of the cotton industry took some 70 years, and it took a century for industry to adopt the steam-engine anywhere near fully. Only a fraction of that time is needed for developments of similar importance today, such as turbo-jet engines in aircraft and synthetic fibres like nylon.

The rapid development of automation does not necessarily mean that the world is entering a period of plenty in which the supply of goods increases so rapidly that it will become difficult to find enough people to use them. The last two decades have brought unusually fast technical changes, but, so far as can be estimated, output per head in British industry rose by only 5 per cent between 1937 and 1948(35) and by 20 per cent between 1948 and 1954. The figures for the U.S.A. have been of the same order. Clearly, the high speed of technical change is not yet overwhelming.

Nor is automation solely responsible for the speed of change; new materials and other new processes are just as important. Also, the economic aspects of automation can be discussed only in the most general terms, because little information has been published and the science of economic prediction is not sufficiently advanced. The following survey of the main problems is subject to that severe limitation.

HOW WILL ECONOMICS CONTROL THE RATE OF DEVELOPMENT?

Many firms that have introduced automatic techniques will freely admit that they began with much faith in them but with little certain knowledge as to their profitability. Decisions had to rest largely on intuition so long as the relative costs of automatic and traditional machines were not properly known. Thus, progress with automation during the present exploratory period will depend very much on the willingness of individual firms to take the first imaginative steps, and that depends in turn on psychological factors, like the urge to be technically up to date and an optimistic assessment of future markets, rather than on a certain knowledge of costs.

The relative importance of the different factors is not known. A research project into the factors governing the application of scientific research in industry is being conducted by the Science and Industry Committee of the British Association for the Advancement of Science. A number of other relevant projects are being carried out by various organizations.

In the long run, however, automation will make progress wherever it has demonstrable economic advantages over existing processes and equipment. Pioneers may

take risks, but ordinary managements will want a reliable basis for their decisions and will keep a close watch on the ways in which automation affects production costs. For this reason it is necessary to study the cost and operation of existing automatic equipment very closely before attempting reliable statements on future trends. (Appendix II briefly describes a few case-histories.) Indeed it seems that information on costs may already contribute more of value to the study of automation than a further exposition of its technical possibilities.

It is possible to identify some important economic advantages of automation. There is the saving of labour directly employed on the process (against which must be set the higher cost of maintenance, of other indirect labour and, possibly, of writing off capital). Other factors may be even more significant; for example, automatic control may reduce costs in some cases by lowering the proportion of scrap that is produced, of parts that have to be re-worked, or of packages that contain more items than was intended, and it may enable goods of better quality to be produced which will command a higher price. What is more, some products cannot be made effectively without automatic control because their manufacture is complex or because serious risks may result from failure to control. Finally, it is likely that electronic computers will be installed in offices because they enable business decisions to be taken on the basis of really up to date figures.

WILL AUTOMATION BE LIMITED TO THE VERY LARGE FIRMS?

Some people argue that automation can be economic only in large firms which produce in great quantities and have big resources of capital. They say that it requires a heavy investment in equipment, that it is technically limited to standardized products, which can be mass-produced, and that it is economically restricted to products that command a large market.

Automation often favours the very large firms on all these grounds, but it need not be confined to them. In deciding for or against it, a firm will probably be guided less by the size of its entire output than by the size of its output of individual products. In industries like aircraft and motor-cars, a large firm buys many components from specialist manufacturers. The supplier, possibly a relatively small firm, may make very few components and can produce them in larger quantities than would the manufacturer of the final product if he made the components himself. Thus, automation suits the relatively small and specialist firms, especially when they are contractors to larger manufacturers.

Small firms, whether specialist or not, may be able to arrange long runs for some components and so facilitate automation. A study of output and sales in the past will often reveal the possibility of planning production in one of the following ways: (i) limiting production to a few types of component at any one time, switching it to new types when stocks are large enough to meet the expected demand for a while, and switching it back again when stocks run down; (ii) making one basic type of component, but selling it in a variety of models with different finishes and attachments; or (iii) mass-producing some of the main components. Each firm needs to make its own statistical analysis in order to discover which of these alternatives is suitable.

Some small firms may have wide scope for producing "matched" components which can be assembled in different combinations, like the components of a child's constructional set, so as to produce a variety of finished goods. Also the control of

machine-tools by computers diminishes the need for long runs and may encourage the growth of small firms with a high ratio of capital to labour.

In general automation should encourage manufacturers to simplify and standardize their products, especially components, so as to reduce costs as far as possible when adopting the new techniques. Individual firms will usually discover how far they should carry standardization by studying simultaneously their methods of production and the expected patterns of demand for their goods.

The high capital cost of automatic equipment need not rule out the smaller firms, though it may present them with financial problems. Capital costs vary widely according to the type of automatic equipment, and some equipment is not beyond the financial resources of small firms. The highly specialized transfer-machine is very expensive, but standard units can now be assembled in transfer machine-lines (the Austin Motor Company has already done so because its tool engineers realized that British motor-vehicle manufacturers, being unable to produce on such a big scale as U.S. firms, need flexible tools) and in this way the capital cost can be reduced and spread over a longer period. The big electronic digital computers are also expensive and are suitable only for large firms; but smaller and cheaper, if less versatile models are already on the market. Also, small firms can hire computer services or make co-operative arrangements with other firms. Automatic devices for process-control vary widely in cost, but small firms can afford the cheapest of them.

There are technical, as well as economic reasons why automation need not be confined to large-scale, repetitive production. Transfer-machining is being made more flexible (by the use of standard units, among other methods) and the economic importance of very long production-runs is declining accordingly. In process-control each automatic mechanism, though it regulates only one condition, can be adjusted so as to give control at any desired level within a range and, consequently, to permit minor variations of product in some industries, especially the process-industries. (The building-board factory described on pages 10–12 is a good example.) Electronic digital computers are also versatile and machine-tools controlled by them can produce a wide variety of components. As soon as a computer can be used as a master controller in a factory, over-all control will be both automatic and flexible—though how flexible will depend on how versatile the individual process-controls or machine-tools have become.

There is then no valid economic reason why those medium and small firms that are technically and commercially progressive should not use some automatic techniques of production. Indeed, the progress of automation will sometimes encourage the growth of small firms that specialize in a limited range of components, often as a service to the manufacturer of the final products. This is because size of market is a better guide than size of firm to the possible economic advantages of automation. Automation will also encourage a general increase in specialist services, such as the computer services mentioned above. These factors may modify the general trend in the structure of industry, which is towards large, highly capitalized undertakings with complex technical processes, and which has many causes besides automation.

Expanding firms are more likely to make use of automation than contracting firms, as many of them need to buy new plant in any case in order to increase production. What is more, they can probably accumulate or attract capital better than many other firms. Also the newer industries are likely to be more interested in automation than the old ones, partly because they are expanding, but also because they are less likely to be hampered by conservative managements or by a labour force that fears to lose its traditional skills (see Chapters IV and V).

Finally a firm's interest in automation will depend partly on how far and how often it has to re-equip its factories. It is more likely to introduce automation if it has to replace a whole line of machines at once, than if it can change them one by one. Similarly it will favour automation more if it has to re-tool its machines often, not occasionally.

WHICH INDUSTRIES WILL BE MOST AFFECTED?

It is apparent that little precise information exists on how economic factors will influence the course of automation. But the technical possibilities discussed in Chapter II can be examined in the light of economic principles and tentative and general conclusions can be reached as to which industries are likely to be affected.

Automation is not expected to have a great impact, at least in the foreseeable future, on a large section of the economy, including agriculture, forestry and fishing; mining and quarrying; clothing (not textiles); building; professional services; entertainment, catering and domestic service. Some of these industries, for example, agriculture, mining and building, will employ new machines and new methods of mechanical handling, but automation will probably not solve their main technical problems.

Steady development can be expected in most remaining industries but in some cases they will affect few basic operations and a very small fraction of the employees. For example, although automatic signalling is already widely used in transport, and automatic telephones in communications, in neither industry has the majority of the labour force been involved. The main areas of possible development are grouped below under the headings of Chapter II.

AUTOMATIC MACHINING

The two major developments in automatic machining—transfer-machining and the control of machine-tools by computers—differ technically and in the way in which they make automation economic. Transfer-machining depends on long production-runs and so is confined to industries with a large and steady demand for components of standard design—that is to say, to most of the industries that produce durable consumer goods on a large scale. Tables I and II show that there has been a rapid increase in the output of motor-vehicles, refrigerators and washing machines during the last ten years. Table I shows that the output of motor-vehicles has soared upwards without a corresponding increase in the labour force—a good example of an expanding industry using labour-saving machinery. These industries are likely to use transfer-machines even more extensively in future, as the demand for their products, being linked to the rising standard of living, will probably continue to rise despite fluctuations.

Automation may be economic in other industries with big markets, especially now that standard units can be assembled in flexible machine-lines. Examples include industries producing agricultural, mining, textile and other production-machinery, stationary engines and office machinery. Industries that use presses widely will probably develop a system of flow production based on automatic transfer and automatic loading, operation and unloading of presses. This is already happening in the motor-vehicle industry, where long runs make it economic.

The control of machine-tools by computers will be first used in small-quantity production and in the tool-rooms of large engineering concerns. It can be employed

Table I: Output and Employment in the Motor-vehicle and Aircraft Industries

Year	Production					Employment			
	All vehicles	Motor-Cars	Commercial vehicles, buses, etc.	Motor cycles	Pedal cycles	Motor vehicles and cycles		Aircraft	Parts for motors and aircraft
	Index 1948 =100	Thousands			Millions	Thousands	Index 1948 =100	Thousands	
1935		338	91	65	2·0				
1946	87	219	165	93	2·1				
1947	91	287	173	112	2·5				
1948	100	335	192	134	2·9	279	100	144	92
1949	111	412	233	153	3·5	292	100	151	95
1950	121	523	280	171	3·5	297	100	149	115
1951	124	476	279	172	4·0	299	100	162	124
1952	124	448	268	158	3·6	299	107	196	139
1953	138	595	277	154	3·0	294	105	215	143
1954	155	768	306	179	3·3	311	112	230	157

Source: Central Statistical Office: *Monthly Digest of Statistics*, London: Her Majesty's Stationery Office

Aircraft have been included in the *employment* section of the table (but not in the *production* section) because motors and aircraft are not separated in the figures of employment on the manufacture of parts.

It can be estimated from the index of production that output per man in the vehicle industries rose by 30 per cent between 1948 and 1954. A small part of it may be due to increased purchases of components. The average weekly working hours per operative rose by only 4 per cent over this period.

in the production of components for aircraft and in the experimental departments of other factories. There are less clear advantages in using computers to control machine-tools producing in large quantities, as distinct from the manufacture of prototypes. They make some saving in costs becaues they enable manufacturers to

Table II: Output of Domestic Refrigerators and Washing Machines

Year	Refrigerators	Washing-machines	
	Value, £ thousands	Numbers, thousands	Value, £ thousands
1947	3 600	—	—
1948	6 833	144	3 652
1949	9 303	296	6 989
1950	11 875	537	11 778
1951	14 784	715	16 106
1952	11 751	496	12 136
1953	12 501	592	14 497
1954	16 359	841	22 146

Source: Central Statistical Office: *Monthly Digest of Statistics*, London: Her Majesty's Stationery Office

dispense with jigs and fixtures; hut this saving may be outweighed by the additional cost of making machine-tools as accurate in operation as the existing machines are with the help of jigs.

AUTOMATIC PROCESS-CONTROL

Automatic control of processes is already common and will prohably spread wherever production can be organized as a continuous flow of material which responds under control to changes in the conditions of production. The extent and speed of development will depend on economic factors. Usually the economic advantages of automatic control are fully obtained only when it is designed as an integral part of new plants; and the greatest advances will probably he made hy large firms that are able to finance big programmes of investment.

Automatic control of production machinery will continue to be improved in industries like iron and steel, printing, and textiles (spinning, weaving and knitting). Again, economic factors will mainly determine the extent of development. To take one example, the governing factor in steel-rolling mills will probably he the rate at which firms can invest in entirely new plant.

Automatic control will also he extended to ancillary processes, like inspection and handling, in many industries where the basic manufacturing operation will remain unaffected.

AUTOMATIC PROCESSING OF DATA

Electronic digital computers are likely to be used where routine information has to be analysed rapidly and on a large scale. The handling of information is a central feature of service industries, like banking and insurance, and all very large manufacturing companies probably handle enough of it to justify the installation of a computer. So there is a big potential field of application in large offices. Small firms can frequently make use of the hiring services provided by the companies that manufacture computers.

WILL IT BE DIFFICULT TO RAISE ENOUGH CAPITAL?

In 1954 the United Kingdom spent £2500 million on capital goods (gross fixed capital formation). This was 16 per cent of the gross national product, compared with 13 per cent in 1938. In the U.S.A. the 1954 proportion was only 14 per cent, hut the gross national product per head in the United Kingdom was three-fifths of the U.S.A's and so the United Kingdom formation of capital per head was only two-thirds of the U.S.A.'s

Table III shows that the United Kingdom devoted an increasing proportion of a rising national product to capital goods hetween 1948 and 1954, hut that the capital goods bought hy manufacturing industry have taken up a decreasing proportion of a rising national product since 1951, though they have changed little in ahsolute amount.

Will the spread of automation require an increase in the rate of capital formation and, if so, will it he easy to raise the capital? Very little is known concerning the amount of capital needed for automation. In one widely quoted case it has proved cheaper to construct a transfer-machine than to huy the equivalent number of standard machines, and the transfer-machine has a higher output than the conventional machines would have. (38) (See Appendix II, page 83). In so far as this case is typical,

Table III: Gross Domestic Fixed Capital Formation in the United Kingdom, 1948–54

	1948	1949	1950	1951	1952	1953	1954
As a percentage of the gross national product							
All fixed capital formation . .	13·5	14·0	14·4	14·4	14·7	15·6	15·6
Fixed capital formation in manufacturing industry . .	3·35	3·58	3·96	4·16	4·06	3·84	3·72
Plant and machinery in manufacturing industry. . .	2·16	2·35	2·65	2·88	2·72	2·63	2·38
At 1948 prices, fixed capital formation in manufacturing industry (£ million) .	348	384	427	438	416	417	422

Source: Central Statistical Office: *National Income and Expenditure* 1955, London: Her Majesty's Stationery Office, 1955

automation can reduce the amount of capital needed for a given output of goods. But it is likely nevertheless to increase expenditure on capital goods in a year, partly because it implies rapid technical progress, which will render machinery obsolete more quickly and so shorten its working life, and partly because output will increase with automation and more machinery may be needed to produce it.

How can the expanded demand for capital be met? This question must be considered as two: what changes will be needed in the division of the gross national product, and how will individual firms obtain the funds they need for the purchase of equipment? Since 1946 the gross national product (at constant prices) has risen by an average of 3 per cent a year and, if this trend continues, it will be possible to invest more each year in new plant for industry without diminishing the share of national product that is used for other purposes, notably house-building and the consumption of goods and services. Moreover, the proportion of the national product that is spent on industrial plant is so small that it can be substantially increased without halting the rise in the volume of expenditure for other purposes (though their proportion of the national product must fall). Thus, in terms of national accounting, there should be no difficulty in finding enough resources for investment in automation. But if a falling proportion of the national product is spent on consumption and on non-industrial investment, manufacturers may be less inclined to expect a continuing rise in output and may lower accordingly the rate at which they install new equipment.

What of the supply of capital to individual firms? Most manufacturers in the United Kingdom obtain most of their capital for new equipment from their own reserves and from the sums they have set aside for depreciation. This is particularly true of the large corporations, which have contributed the main developments in automation. In other words automation has so far formed part of the normal programmes for capital replacement and re-equipment and has been financed largely out of resources built up for that purpose. Progress with automation will probably remain gradual, as with other advances in technique, and as a rule it will not make excessive demands on the capital resources of individual firms. By making production

cheaper, automation should enable most firms to reserve enough funds to cover their increasing needs. Thus it should generate the finances for its own growth, just as mechanization did in the late eighteenth and early nineteenth centuries.

Small firms may be less able than large firms to finance this type of development from reserves, and they may find it more difficult to raise money for large schemes from the usual alternative sources—banks and insurance companies. Some large motor-car manufacturers in the U.S.A. have had to lend money to the suppliers of their machine-tools to enable them to develop new automatic machinery.

Projects for automation have not been introduced to the capital market, but not because capital is scarce for this kind of development. Market flotations are an obsolete method of financing entirely new ventures and are normally made only for the expansion of existing businesses. A number of large equity issues have been successful in the last year or two and this suggests that the market will respond to demands for risk capital provided that they are backed by names and records it knows.

WILL MACHINERY OR MATERIALS BE SCARCE?

There may be a shortage of machinery for automation, even though there are sufficient funds with which to buy it. Since the last war the British machine-tool industry has had full order-books, that is to say it has not produced enough to meet all orders rapidly. For example, the orders for metal-working machine-tools that were on hand at the end of 1954 were equal to fifteen months' output.(29) Rapid expansion of the industry appears to be necessary if it is to be able to be able to supply transfer-machines without excessive delays. Should it fail to expand in time to meet the expected demand automation may be slowed down or, perhaps, more user-firms may follow the recent example of the Austin Motor Company and make some of their own machinery.

The supply of raw materials is often variable and some raw materials have been alternately scarce and plentiful since the end of the last war. The changes have been rapid, and the causes many. It is extremely difficult to predict how one additional factor, automation, will affect the availability of raw materials, or how their availability will influence its development. But some kinds of one vital material, steel, have been scarce since before the last war and shortages like these delay the construction of automatic machinery.

Automation will add to the rising demand for energy, because all saving of labour by machinery, whether it is automatic or not, increases the ratio of power consumption to the numbers employed. Though the new plant uses fuel less wastefully than the old, it will not save nearly as much as will be needed to supply the extra power. The industrial consumption of electricity rose by 160 per cent between 1938 and 1953 while the total industrial output increased by only 60 per cent; and the consumption of fuel in general can be expected to rise by ever increasing amounts. Already there is a chronic and growing shortage of coal, and new sources of power must fill the gap.

WILL THERE BE A SHORTAGE OF MANPOWER?

Though automation saves labour on the whole, it increases the demand for skilled managerial and technical manpower and it is likely to be slowed down by the existing and prospective shortage of technologists and scientists. (The present distribution of scientists and engineers in Great Britain is the subject of a survey which is being

carried out by the Ministry of Labour in co-operation with the Department of Scientific and Industrial Research. The findings will include information on the extent of the present shortage of manpower in these groups and a forecast of the probable demand in three years' time).

The supply of skilled technical manpower is very inelastic because a long period of training is needed, because the institutions for higher technical education can respond only slowly to industrial needs (even when stated, and it is difficult to state them precisely), and because a limited number of people have enough intellectual ability. There is an urgent need to define future training and educational requirements and to consider how they can be met.

The broad requirements are two:

1. Training of engineers and technicians to give them a specialist knowledge of the techniques used in automatic production.
2. Training in management for those who will have over-all control of automatic processes.

ENGINEERS AND TECHNICIANS

For a thorough analysis it is necessary to know how many engineers and technicians will be needed for work on automatic processes and what types of training they require. This information can be obtained only by assessing the likely trends of automation in detail for each industry, and that assessment has not yet been made. Even so the problem can be given immediate consideration. The urgent need is to determine the kinds of course to be given, find the necessary teachers, and start the courses as soon as possible.

Engineers with a variety of technical backgrounds will be needed to man automatic processes: "control" or "systems" engineers who have a wide knowledge of techniques of control; engineers versed in both mechanical and electrical engineering and who will introduce techniques of control to traditional engineering processes; production engineers, who have a knowledge of statistical techniques and who will obtain the best possible performance from complex systems of machines; tool engineers, who can find the most economical and labour-saving methods of machining components; and, of course, electronic engineers.These future requirements strike across the existing boundaries of professional training and although some new courses meet them in part (see Appendix III on page 87) they have to be systematically appraised.

The same is true of the training of junior technicians and craftsmen. Though special courses in electronics will be needed (like the courses that helped to develop the electrical and radio industries), it is equally important to provide a broad vocational training, which will permit a flexible deployment of technical manpower, both in individual firms and in industry as a whole.

Industry may have to take much more direct action than in the past to secure the technical training that its future specialists will need. New courses will be wanted at the universities and technical colleges, but there will be a complementary demand for training that is tailored to meet the needs of individual companies and industries.

MANAGERIAL STAFF

Training for the management of automatic processes is linked with the training of technical manpower, because these processes break down the distinction between technical and managerial skills. Managerial decisions are vitally important when they

affect the maintenance and operation of integrated plant and they can be taken only by persons who know the plant intimately as a technical system. Control will tend to pass into the hands of technical specialists and the institutions for higher technical and scientific education will be asked to train students for management more than in the past. Automation will, in fact, reinforce a need that already exists because of the growing complexity of modern factories.

Automatic production is also likely to increase the advantages of a formal training in management, because each plant must operate as a unified whole and this is best achieved by techniques of managerial planning and control, which have to be acquired by formal training. Industry may need to take steps to secure adequate facilities for this, as well as technical training, and the universities and technical colleges will be expected to contribute much more than in the past.

WILL THERE BE SOCIAL RESISTANCE TO AUTOMATION?

It is often said that progress with automation may be held up by resistance from those whose skills will become redundant. The likelihood of redundancy is considered in Chapter V (page 64) and the tentative conclusions are reached that automation is not likely to displace labour on a large scale if it is introduced with foresight and planning, and that, if full employment persists, displaced labour can be quickly re-absorbed in other work.

Some traditionally minded managements may also slow down progress with automation—indeed with innovation in general—because of their conservatism. Managerial scepticism towards new and radical developments in technique is natural and healthy up to a point, especially when it causes the economic aspects to be considered at length. If scepticism is to be overcome, the scientists and technologists concerned will have to make clear both the technical possibilities of automation and its implications for industry. If they fail, it will not be surprising if managerial conservatism and scepticism keep the rate of technical change below what is economically desirable.

CONCLUSIONS

Many industries will adopt techniques of automatic production in one form or another. It is uncertain how far and how fast automation will go, but the technical possibilities are great in both factory and office. Neither size of firm nor availability of capital seems to be a principal restriction, though progress will be most rapid in the bigger firms because they have the advantages of larger-scale production and larger financial resources. The shortage of trained managers, engineers and technicians may be the most decisive factor. It arises because the technical complexity of industrial production is increasing, partly through automation, and there are not enough scientists and technologists to go round. This problem is already so important that a major reappraisal of university and vocational training in this country may be necessary.*

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* Research into "Industry and the University Graduate" has just been completed by P.E.P. (Political and Economic Planning) and the results will be published soon. (See Appendix V).

The Impact on Management

AUTOMATION need not seriously affect the traditional problems of management until it is extensively used in the factory. This chapter is, therefore, mainly concerned with factories that have reached, or will reach, that stage. It does not cover all the implications for management (as they extend to every routine managerial function) but only the most significant of them. Nor does it review the implications in detail for all the industries concerned. It makes a number of general arguments and illustrates them almost entirely from the engineering industry, where automatic processes are novel and the new problems of management are widely debated. But most of the arguments apply equally to the process-industries and other manufacturing industries, where automatic processes have existed for some time. Many of them are also relevant to other kinds of technical innovation.

The use of automatic techniques of production has three main consequences, so far as management is concerned.

1. an increase in the *technical complexity* of production;
2. a *technical integration* within processes by which, for example, machines are linked and components or materials are enabled to flow from one machine to the next; and
3. *high capitalization*, with machinery taking a bigger share, and labour a smaller share, of the costs of production.

These trends result from any kind of mechanization, but they are strikingly intensified by automation. They increase the responsibilities of management by requiring a heavy investment of capital and a high rate of output, and by making plants more inflexible in terms of what can be produced. They increase, in fact, the need for planning and control of a very high order.

This is the main implication of automation for management. It will be more important then ever before to plan the construction of a new plant well in advance. Each piece of equipment has to be carefully chosen with the needs of the whole plant in mind, because unsuitable equipment can lower the efficiency of the entire system. The possible techniques of automatic production should be considered when working out the design and the precise function of a product. Likely trends in demand should be studied with a view to discovering how adaptable the equipment needs to be.

Planning is equally necessary once a plant has been established, its main task being to maintain a high output by devising suitable programmes of operation and changing them when necessary. Three organizational tasks are essential: to overcome the technical inflexibility that occurs in automatic plants, as in all highly integrated plants where processes and machines are linked together; to find an adequate system for the maintenance of automatic equipment; and to arrange, where appropriate, that automatic processes run continuously.

Automation also implies important changes in the techniques of management and lays emphasis on the need for systematic study of industrial operations and for control of costs.

Above all the structure of management is likely to be drastically changed, since new types of management demand new types of managers and new qualifications for the jobs. Technical knowledge and training will be much more widely required than before; so will two human qualities—versatility and adaptability. The need for communication and co-operation in industry will be greatly increased.

These managerial aspects of automation are reviewed briefly in the following pages.

PROBLEMS OF ORGANIZATION

TECHNICAL INFLEXIBILITY

The transfer-machine, which links many machine-tools in an automatic production-line, best illustrates the problem of technical inflexibility in automatic processes.

Example: Transfer machine-line

The time taken by each of a series of consecutive operations by a machine on the same component will differ from operation to operation for obvious reasons. The time spent at each station will be decided by the largest individual operation. At all other stations the tools will not be used to full capacity. If the larger operations can be speeded up the line will work more efficiently and output will rise.

When tools wear out or machines break down, production is stopped throughout the line. This loss of production-time, "down-time" as it is called, can be extremely serious, as there are many points on the line at which stoppages can occur, and loss of output through stoppages cannot be recovered on any line that normally works continuously. It is a principal task of management to keep down-time to a minimum by increasing flexibility.

There are several methods by which that may be attempted. One is to construct a siding by the production-line so that a stock of components can be built alongside any machine when the following machine is stopped, and can be depleted when the preceding machine is stopped. This method may be suitable when the components are inexpensive and stocks can be held, if necessary, all along the line. (It can also be used to provide storage-bunkers at various points in continuous-flow production.)

A second method is to provide spare machines: it is suitable where machines are not very expensive or are liable to break down often.

A third method, and possibly the cheapest in the long run, is to match the endurance of the various cutting-tools better. This is simple when only a few machines are linked, but a transfer-machine of twenty or thirty units yields complex data concerning cutting speeds and rates of wear and break-down, and statistical techniques may be needed for an effective analysis of them. There is in fact a need to find out whether current statistical techniques are adequate when studying problems of synchronizing automatic machine-lines. Considerable attention is already given to these problems in the U.S.S.R.(47, 53, 58, 63, 65)

MAINTENANCE

Automation increases the importance of maintenance as a function of management, whether it is done by the makers or the users of machinery. It also emphasizes the need for preventing faults, as distinct from repairing them, so as to minimize the number of stoppages and to achieve, as far as possible, a high and constant rate of output.

Preventive maintenance must be based on an informed estimate of how machine-tools will perform; for example, what their relative speeds will be, how often they will wear or break down, and in what ways the quality of their work will decline as they wear. Analysis of performance will show which tools are liable to break down at random, with or without signs of wear or poor performance; which of them gradually wear out and then fail to meet requirements at a time that can be predicted within limits after analysis; and which parts will never wear out over the period in which the plant is likely to be used. The findings of such an analysis will provide the basis for future policies of maintenance that are designed to obtain the fullest possible use of automatic machinery.

CONTINUOUS RUNNING

It may be necessary to run automatic machinery continuously, either because it is costly to shut down a plant (in some process-industries, for instance) or because the ratio of capital to labour is high and the capital equipment needs to be employed as fully as possible.

Continuous operation raises several important problems and involves new costs. It depends on the availability of workers for shift work and managements may have to arrange special amenities like meals and transport at their own expense. It also depends on making adequate provision for the maintenance of plant. This is often not easy, for instance when a machine has to be stopped for maintenance; but even where continuity is impossible, a plant can be worked for two shifts and closed down for maintenance during the third. A good example of this practice in a near-automatic factory is given on page 10.

Research into the economics and the social implications of shift working is being done separately at the Universities of Cambridge and Sheffield. (See Appendix V).

PROBLEMS OF TECHNIQUE

STUDY OF OPERATIONS

In pre-automatic processes, where output is controlled by the human operator, incentive schemes based on output are used to stimulate effort, just as training schemes are used to develop skills and time-and-motion studies to improve working methods. New techniques of management are needed when output is automatically controlled; chief among them will be a systematic study of operations (sometimes known as "operational research"), conducted as scientifically as circumstances permit. Even fairly elementary study often makes it possible to forecast the likely consequences of difficult courses of action, and advanced techniques can be applied to complicated problems of forecasting. In addition, it is often desirable to analyse past actions so as to find features that can be improved and to refine methods of planning and forecasting.

Five appropriate fields for research are listed below.

Wear, breakdown, and other characteristics of performance (referred to above). Such analyses are made regularly in air-line companies, and in a few big manufacturing firms. It is very difficult, particularly where breakdowns have a random element, to see the pattern of operation and to formulate the best policies for maintenance, for manning, and for holding spare capacity, unless accurate records are kept and systematically analyzed.

Pattern of demand. The demand for the whole output of a firm and for the output of each product is likely to vary. It may be possible to foresee the variations fairly closely for a long time ahead or, if not, to see statistical regularities in them and base on them a policy designed to maximize the expected profit (in the statistical sense), or to minimize the risk of a heavy loss, or to achieve some other possible optimum. The pattern of orders may allow a variety of procedures. A number of individual products can be made full-time by automatic processes, if others are dropped or are produced in batches, as they were before automation. Alternatively, a number of products may be assembled from mass-produced parts; or a moderate number of products may be mass-produced in batches, either for stock or for customers who pay a lower price in return for a longer delivery date and so allow several orders to be lumped together. The expected variations in orders will have a fundamental effect on the amount of flexibility that must be allowed for when planning a plant.

Optimum stockholding. Research can help to balance the cost of holding stocks with the losses due to inability to fulfil orders. Investigation of the real costs of stockholding may be important.

Scrap records. The aim is to find out how far automatic control of tools can refine their work and reduce scrap; and how far the saving of scrap balances the cost of automatic control.

Combinations of products. Study can be made of the possible ways of overcoming difficulties in producing certain combinations of products—difficulties that arise partly from technical causes and partly from the balance of existing plant.

Some managerial decisions cannot be postponed until all the appropriate information has been obtained and analyzed. But when operational studies are being made continuously, up-to-date information should be currently available. Also if research-workers and managements keep regularly in touch with each other, they will very likely see the need for information early enough to allow time for special investigations.

USE OF COMPUTERS[46, 111]

Electronic digital computers can help (and modify) management in two important ways as a result of their capacity to store large amounts of information or do large amounts of computation with it (see pages 38–9). First, they can replace clerks on routine calculations, such as working out pay-rolls, so saving time, manpower and administrative overheads, Second, because they work fast and handle intricate data, they may do calculations that were not formerly feasible. In one instance, a U.S. distributing organization can feed to a computer the returns of stocks at each of its branches and so view its stock position complete, up-to-date and in as much detail as is needed. Formerly it had to use sample figures and these, when ready, were out of date by ten days or more.

Using a computer, a firm could make and compare very detailed budgets for alternative schedules of future sales and production and could find which seemed to be the most profitable. If it studied operations systematically on the lines described earlier in this chapter, it might be able to use past experience of fluctuations in demand as a basis for assessing future probabilities. In this way it could estimate both the profitability of a schedule, if all goes well, and the risk of all not going well.

If such possibilities are to be realized, managements will need sufficient understanding of what a computer can do to follow proposals for new uses; and those who work out proposals will need to keep in touch and sympathy with the aims of management. The main object is not to find uses for the computer, but to further the efficiency of management. For example, there have already been cases in which analysis of office procedures prior to mechanization has made great savings possible merely by streamlining work (see Chapter II, page 38). Sometimes the savings have been so great that it is no longer necessary to introduce a computer.

CONTROL OF COSTS

It is apparent from the preceding discussion that those who do research into operations must collaborate closely with cost-accountants. For one thing, cost-accountants will have to supply research-workers with much of their information. On the other hand, automation, by changing the balance of costs, may throw up problems of method in costing that cannot be solved without studies in the factory.

One result of the change is that maintenance and amortization form a much higher proportion of costs than before. As a result, there may have to be a change of emphasis in ways of comparing and controlling costs. Rule-of-thumb methods of allocating overheads make an adequate basis for fixing prices, but they can be grossly misleading when used in estimating the real cost of alternative methods of production. Suitable methods of costing may have to be developed in the light of studies on the shop floor so as to distinguish between costs of three kinds; those that arise from the amortization and servicing of capital (they enter into consideration only when there is a question of investing in new plant, but they may accrue even when a machine is left idle); costs, like maintenance and consumption of power, that arise directly from the operation of the plant, though they are generally classed as overheads; and the cost of labour directly involved on production. (Note that the distinction between direct and indirect labour may lose its relevance in a highly-capitalized plant).

For similar reasons, a plant with a high ratio of capital to labour will need different indices of control and efficiency. Indices showing the utilization of machines and the proportion of down-time due to breakdown, lack of work, or other causes, will become much more important than formerly, but the index of output per head will be less important. The attention of the production engineer will have to be diverted from questions of output per head, control of labour and incentives to questions like the utilization and the rapid and efficient maintenance of machines.

CHANGES IN STRUCTURE

Since the Industrial Revolution began, changes in the techniques of production have transformed the structure and organization of management. This is largely because firms have grown in size, but also because different structures of management suit different technological processes. For example, the mass-production techniques developed by Henry Ford could not be operated by a structure that had been developed for production in batches. There is always a danger that new techniques in production may be hampered unless the structure of management is changed appropriately.

This section reviews some of the ways in which automatic processes appear to call for new structures of management. Many of the new problems have already been encountered and overcome in the process-industries, which probably have much to

teach firms that are new to automation. (Research into the structure of management in industries with different technical processes, including some with highly automatic processes, is being done by the South-East Essex Technical College. See Appendix V).

ROLE OF THE TECHNOLOGIST IN MANAGEMENT

Automation, in common with other developments that make techniques of production more complex, requires that scientists and technologists should find their right place in management, because technical considerations affect an increasing number of policy decisions on investment and on the routine operation of plant. The need is two-fold: for managements to have a broad understanding of the new principles emerging from scientific and technical developments, and for technologists and scientists to see more clearly the economic and other managerial factors involved in implementing their advice.

It seems likely that scientists and technologists will become members of the top-management team more frequently than in the past. In addition, some functional departments are likely to become more important than they have been. For example, the importance of maintenance will increase if the cost of down-time becomes prohibitive. Above all, the design and manufacture of products will need to be much more closely integrated if the best use is to be made of automatic methods of production. These structural adjustments are likely to be achieved most smoothly where the technical departments already have an effective voice in management; but difficulties may be encountered where these departments have been traditionally "on tap but not on top". The effect of technical innovation on the structure and organization of management is part of a research project on change and adaptation in industry which is being conducted by the Social Sciences Research Centre, University of Edinburgh. (See Appendix V).

THE "LINE AND STAFF" PRINCIPLE

The acquisition of managerial responsibility by the technician is one facet of a more general change in the structure of management—the weakening of the "line and staff" principle which, though traditionally used in mass-production, may need to be closely re-examined to see whether it is suitable for automatic processes or whether new principles are more appropriate.

The principle has, in fact, two possible disadvantages, the first of which concerns communication within the factory. Two types of rapid and effective communication are needed in automatic processes: first, between the machine-minder, maintenance personnel and technical specialists in the event of a machine breaking down; and second, between the various technical specialists who set up the plant and correct faults in its operation. If the structure of management impedes communication of either kind it may have to be changed.

There are reasons for believing that the "line and staff" principle is a case in point. When faults need to be remedied quickly, the machine-minder may have to draw on his intimate knowledge of his own piece of equipment or process and call in the right specialist department without going through the chain of authority on the line. In cases like this the essential working link is between the operator on the line and the technician, and the job of the foreman may be drastically modified. He may be less concerned with decisions that affect production than with keeping records

such as the level of stocks and the number of shifts worked. He will, moreover, be less needed in his role of "man manager", as discipline will be provided more by the technical process, through the occurrence of faults, and less by managerial control.

A second general disadvantage of the "line and staff" principle is that it encourages the growth of separate and rigid functional "empires", with ideas and objectives that are determined as much by specialist and professional interests as by the needs of the firm. Automation requires technical experts to be flexible and co-operative, rather than rigidly specialist and competing. It is not yet known whether an alternative structure of management could fulfil this need better than the "line and staff" principle.

COMMUNICATION AND CO-OPERATION WITHIN MANAGEMENT

The foregoing review emphasizes the need for close co-operation between technical experts in the management of automatic processes: for quick solution of the technical problems of maintaining plant; for new techniques of management like the systematic (and often statistical) study of operations; for compressing the time taken on research, development and production, so as to bring products based on new technical ideas quickly to the market; for integrating product-design and the planning of facilities for production; and for relating sales-forecasting closely to the technical planning of automatic production. Objectives like these will be reached only if the specialists exchange information freely and rapidly and reach effective decisions jointly.

Thus, co-operation within management will be at least as important as the co-operation between management and workers that has been greatly emphasized in the past. There seems, moreover, to be no reason why the experience gained in improving relations between management and workers should not be applied with equal benefit to problems of co-operation within management.

Communication within management may also be affected if electronic computers are used to digest a large amount of numerical data and to provide indices that can give warning of necessary managerial action. The use of these indices can enable managements to control operations more effectively and may increase the number of men that a manager can supervise.

MANPOWER REQUIREMENTS

PLANNING OF REQUIREMENTS

The growing speed of technical innovation makes forward planning more necessary than in the past. Plans should include, among other things, estimates of manpower requirements. In recent years there has been much talk of resistance by labour and management to technological changes, and there is a growing appreciation of the need to preserve sound human relations during the period of change, and especially to inform and consult workers in advance.

Resistance to automation may be difficult to combat, if it is based on the belief that redundancy cannot be avoided. The possibility of avoiding redundancies is discussed in Chapter V (page 64). No tactical approach, however wise, is likely to win the consent and willing co-operation of those whose jobs are threatened. But a sharp clash of interest over redundancy can often be avoided if problems of manpower are considered, as an integral part of forward planning, well in advance of expected crises.

The planning of manpower is based on several factors: predictions of future technical developments within a firm or industry, taking account of economic factors; an assessment of the skills required to operate the new technical processes; information on possible sources of manpower; and a long-term plan of training which will enable the demand for and supply of manpower to be reasonably balanced. Forward planning is necessary because it is becoming increasingly difficult to adjust supply and demand over a short term. Skilled labour is scarce: and the higher the skill, the longer the period of training and the greater the time-lag between the recognition and the satisfaction of a need. On the other hand where labour is suddenly made surplus, it may be difficult to re-absorb. On both counts automation emphasizes the need to look ahead if demand and supply are to be kept in balance.

INDUSTRIAL TRAINING SCHEMES

One potential result of planning for manpower is that training requirements can be stated well in advance. The requirements for automatic processes must vary from firm to firm but, broadly speaking, they are likely to involve training on the job for semi-skilled labour, the creation of a deeper technical understanding among craftsmen, and the provision of more highly trained managers and technologists. The new skills required of operatives and craftsmen are discussed on pages 67–75, and the new specialist requirements for technologists and managers on pages 66–7. In this chapter, the main changes are summarized in order to emphasize how widespread the need for training within industry is likely to be.

Operators. Workers on automatic processes will cease to operate machines directly and must learn to interpret instrument-readings and other signals, to decide when instruments are not working properly, to observe smaller deviations from normal working than are usual in non-automatic processes, and sometimes to exercise greater responsibility in stopping machines or processes. Training on the job will often be necessary to secure adequate performance. It will also be needed in offices where electronic computers are introduced.

Craftsmen. The production and maintenance of automatic equipment will undoubtedly require new craftsmen, such as electronic technicians, and the broad theoretical basis of craft-training may become more advanced. Firms may have to deploy skilled craftsmen on different tasks, and training courses including the traditional apprenticeship schemes may have to be modified so as to encourage greater flexibility of skill. Research into apprenticeship is being conducted by Bedford College, University of London, and by the University of Bristol. (See Appendix V).

Technical specialists. Technologists are likely to have more managerial responsibility and will need a better understanding of the problems involved, especially the factors that make the new techniques economic in operation. They may also benefit from training in human relations, because it is important for them to co-operate with other specialists. The technical qualifications required for work on automatic processes cut across the existing boundaries of professional and technical education (see page 53) and firms may need to provide more training for specialists than in the past.

Managers and supervisors. It has been emphasized in this chapter that automation will modify the present role of managers and supervisors, and in particular that foremen, as controllers of labour, may have different responsibilities for which they may

need re-training. All grades of management will need fuller knowledge of the technical factors that influence their decisions. There may have to be training in techniques of planning and control, as their importance increases; and in ways of using the statistical information provided by electronic computers to improve the quality of planning.

CONCLUSIONS

In this chapter emphasis has been laid continually on the importance of planning as a function of management in factories with automatic processes. The planning of manpower requirements is particularly needed because technical manpower is becoming more and more scarce and because if labour is suddenly made surplus by the advent of automation in one factory it may be difficult to re-absorb in other departments of the same firm without advance planning. The lesson is that good management can do much to soften the impact of automation on labour. The nature of that impact, and of the problems it creates for management, is examined in the next chapter.

CHAPTER V

The Impact on Labour

A NUMBER of important questions are being asked about the effect of automation on workers. Will it raise their standard of living by increasing earnings or reducing working hours? Will the introduction of automation create unemployment? Will more skill be demanded or less? Will workers get more satisfaction from their jobs?

All but the first of these questions are discussed in this Chapter. As for the first, it seems fairly obvious that extensive automation will increase living standards, but how the increase will be distributed cannot be foreseen; it will depend initially on negotiation between employers and workers.

AUTOMATION AND EMPLOYMENT

EMPLOYMENT IN THE ECONOMY AS A WHOLE

Automation can be introduced for a variety of reasons, of which the saving of labour is only one. But whatever the motive, it very often makes substantial savings in operative labour. The fear is sometimes expressed that, since automatic processes increase output per head, the demand for goods and services will be met without fully employing the labour force. This is an understandable reaction, but similar increases in output have already taken place, starting with the Industrial Revolution; and over the long run employment has been maintained, in spite of steadily increasing mechanization, by means of a general rise in consumption and a reduction of working hours. This has not happened, of course, without changes in the distribution of the labour force—from industries producing goods for consumption to those making capital equipment, and from industries producing goods of all kinds to those providing services, such as transport and distribution.

These changes are always taking place; in 1955, for instance, only 465 persons were engaged in production for every 100 in distribution, whereas in 1948 there were 482.[29] Future developments in technology, including automation, will no doubt require similar changes if economic equilibrium is to be maintained. Employment will probably be expanded in the industries producing capital goods (including electronics equipment) and in those industries that provide the services required to maintain an increased standard of living. There is no reason why these changes should not be achieved, like those of the past.

The introduction of automation will be greatly facilitated if a general state of full employment persists in this country, because workers displaced by automation can be readily absorbed elsewhere. Since 1945 there has been a high level of demand for goods and services and many industries have experienced almost continuous shortages of labour. While these conditions exist, there is no reason why the introduction of automatic machinery should generally give rise to more than temporary unemployment, even when the firms introducing the machinery are themselves unable to absorb the workers who are displaced. Moreover, the increase in productivity resulting from automation will help to maintain a high level of demand in so far as it enables manufacturers to reduce prices and to stimulate the demand for their goods. This effect is particularly important in the United Kingdom which depends heavily on its export trade and, consequently, on its competitive power in world markets.

Even when there are more jobs than workers, as with full employment, problems of labour-transfer may arise if the skills or abilities of those displaced do not match the vacant jobs or are not immediately available in the right area. How serious these problems become will depend on the extent and character of the existing mobility of labour. The figures suggest that the normal rate at which jobs are changed is high—one change of job each year for every three workers in employment.* Movement as frequent as this could help to soften the impact of automation; but if firms were to adopt automation at the same time and on a large scale in an industry which is heavily concentrated in a few localities, there might be problems of local unemployment, to solve which it might be necessary to bring fresh industries into the area. Special training might also be needed if particular skills were widely affected; older workers especially might experience difficulty in acquiring new skills.

EMPLOYMENT IN THE INDIVIDUAL FIRM

So far as individual firms are concerned, automation has rarely caused workers to be dismissed, though it very often leads to substantial savings in operative labour. Many managements appreciate the importance of ensuring that their workers do not regard automatic devices as a threat to jobs, and so they try to keep displaced staff whenever possible. Usually those firms that are likely to introduce automation can readily absorb displaced workers for two reasons. In the first place, they will probably be large firms, which can transfer displaced workers to other departments or, if this is not possible, adjust the rate at which the natural wastage of labour is made good. Secondly, automation is making most headway in industries with expanding output, such as electronic equipment, motor-vehicles, chemical products and petroleum. Because labour is scarce, labour-saving methods often provide the only way of expanding production and meeting the demand. Even in industries that are expanding less rapidly, commercial enterprise and technical progressiveness often go hand in hand and firms that pioneer with automation may be able to increase their share of the market for their products.

Much will depend on the speed at which a firm introduces automation. A rapid, general changeover may prevent the absorption of displaced workers, but slower progress is fairly easy to cope with. It must not be presumed that all progress in automation will be fast. In engineering, for example, transfer-machines usually have to be introduced step by step, as each machine is generally designed to produce one component or one narrow range of components. Each component and each new process have to be treated separately and progress is fairly slow. A sensational advance in technique may greatly reduce the labour force on one process, but it may have a very small effect on the whole factory. This has been the experience of motor-car factories so far.

Slow and gradual progress is also usual in offices when electronic computers are introduced, because new methods and routines have to be developed each time a task is transferred from the clerical staff to a machine, and research and development may last several years. Progress may be quickened when the pioneering days are over, as a single computer may then be able to perform many routine clerical tasks that

* Monthly figures are published in the Ministry of Labour Gazette showing how many of the workers employed in manufacturing industry at the end of the month have been recruited during the month. Annual figures can be obtained by adding monthly totals, though they contain some duplication because one person may change jobs several times in a year.

involve calculation (of wages, for example) on the basis of well-tried methods and procedures. When that stage is reached, the introduction of a computer may save the services of a considerable number of clerks.

In the process-industries automatic control is most effective when used in new and specially designed plant. Its use will be extended more by building entirely new plants than by transforming existing plants. In principle, automatic control could displace much labour; but in practice it may not, for two reasons. First, the improvement of quality, reliability and safety is usually more important in most process-industries than the saving of labour, and in extreme cases, like modern chemical plants, there is little labour to be saved over and above the minimum required for emergencies and break-downs. Second, the existence of large firms in many of the main process-industries, particularly chemicals and petroleum, increases the possibility of finding alternative work for the displaced workers in other parts of the organization.

In all industries where automation is likely to be introduced the rate of progress will be governed by the speed with which the necessary technical and managerial skill can be made available. In many cases the speed will be slow enough to ensure a gradual introduction of automation.

When developments including automation are being planned, the manpower problems need to be considered well in advance, along with the technical aspects, so that proper arrangements can be made to deal with them; how, for instance, the displaced workers can be absorbed elsewhere in the firm; how far it will be necessary to take advantage of the natural wastage of labour; and what training will be required to equip the workers either to operate new machines or to work in other departments. Provided these problems are well considered, and provided the trade unions concerned are brought into consultation, so that the workers are kept informed as to how they will be affected and what is being done for them, firms should find it possible to introduce automation with a minimum of disturbance.

THE NEW SKILLS

There have been references in earlier pages to the new skills required in automatic processes and to difficulties in obtaining them. Here the facts and problems are reviewed more systematically and in greater detail. The subject is important because it has been suggested that automation may demote skilled workers by dispensing with their skills; or alternatively that the jobs created by automation are too highly skilled for the displaced operatives to take on, even with training.

THE MAIN CHANGES

Managers and Technicians. It is reasonably certain that the ratio of managers, supervisors and technicians to operatives will be greater in automatic than in non-automatic plants, because processes will be more complex technically and managerial control will have to be stricter. This trend already exists and evidence of it, though fragmentary, is consistent. For example, at the Ford engine-plant in Cleveland, Ohio, where automation has been extensively applied, there is one foreman to 18 operatives; at the Detroit plant, where less modern techniques are used, the ratio is one in 31.[191] In a British steel-making firm, the proportion of managers, supervisors, clerical workers and technicians has grown from 10 to 14 per cent of the total labour force since the introduction of a continuous strip mill. (See Table IV).

Table IV: Impact of the Introduction of a Continuous Strip-Mill on Occupational Structure

(*a*) *Operatives and Maintenance Craftsmen*

	Before, per cent	*After, per cent*
Craftsmen	4	10
Leading hands	15	7
Semi-skilled	55	62
Unskilled	12	15
Juveniles	14	6
Total	*100*	*100*

(*b*) *Managers, Supervisors, Clerical Workers and Technicians*

Increase from 10 to 14 per cent of the total labour force.

Source (*Unpublished*): Department of Social Science, University of Liverpool.
The figures are based on estimates from a sample analysis and so are subject to a small margin of error.

Maintenance-craftsmen. The vital need for effective maintenance in automatic plant has heen discussed in Chapter IV (pages 56-7). One consequence is that the proportion of maintenance men to operatives rises with automation. For example, in the British strip-mill mentioned above, the proportion of craftsmen who directly maintain the process has more than douhled. (See Tahle IV). Automation also makes maintenance-work more skilled. A recent enquiry conducted hy the *American Machinist* among 1574 metal-working companies showed that 22 per cent of the companies had introduced some form of automation and that two-fifths of them had found that they required more skill of their maintenance force.(180)

Operatives. As automation spreads, the lahour force in industries using it will contain fewer operatives and more managers, technicians and craftsmen concerned with building and servicing automatic equipment than it does today. But it is also possihle that the skills of the remaining operatives will he down-graded, leaving less skill on halance than now.

An attempt is made in the following pages to indicate what will happen to operative skills, to illustrate the changes hy a few examples, and to draw tentative conclusions as to how the emerging skills differ from those that they replace. Broadly speaking, automatic processes need two kinds of operative: machine-minders in engineering and other manufacturing industries; and process-monitors, who have long existed in industries like chemicals and petroleum. Machine-minders tend complex and sometimes extensive systems of mechanical equipment, such as transfer-lines and batteries of automatic looms. Process-monitors keep a watch on trends in a given process, usually hy reading instruments.

MACHINE-MINDERS

Machine-minders descend directly from the skilled and semi-skilled machine-operators in traditional mass-production factories. The nature of their work has changed with the evolution of automatic machine-tools and two examples are given below—the semi-skilled operative put on a transfer-line and a skilled weaver put on automatic looms.

Example 1. *Transfer-line for motor-car cylinder blocks.* (Figure 4 on page 17).

(Based on information provided by the Ford Motor Company, Dagenham, Essex.)

The operator on a transfer-line is semi-skilled and is usually paid in the same way as other semi-skilled men. He lifts the cylinder-blocks on to a roller-conveyor and pushes them along the rollers into the loading position on the transfer-machine, pressing a switch to start the cycle of operations. Loading a transfer-machine entails much less physical effort and much less manual dexterity than loading a conventional machine. The operator also observes the progress of cylinder-blocks at the stations in the machine-group for which he is responsible, making a direct visual check or referring to a panel of signal lights. In this way he keeps his group as fully employed as possible. In addition, he must check critical dimensions, fit the main bearing caps and bolts, and place bearing liners in position so that they can be automatically pressed into place. He must constantly inspect the machine visually to see that all operations have been completed and to note failures of tools, such as broken drills and taps, because some installations have no devices for indicating broken or worn tools. He must, in fact, understand what goes on in the transfer-machine without always seeing it. He has to inform his supervisor of any sign of trouble, though if he is experienced he may adjust tool-settings himself under supervision.

The operator on a transfer-line has more to think about than the operator of an individual machine-tool. His actions are more varied and continuous; he may cover more ground, has more points to watch, and must react promptly. He decides when to stop a machine; but a stoppage can very soon affect the whole line and an over-sight can quickly multiply scrap.

Training is carried out on the job under the guidance of supervisors and experienced operators; supervision can usually be relaxed after three or four weeks. It may take longer, however, for a new operator to understand the indicator-panels fully. Success seems to depend more on temperament than on skill, because operators on transfer-lines must be adaptable and conscientious.

The duties outlined in this example may vary from company to company and will probably be further modified as transfer-machines are improved, for instance when machines can be stopped automatically for change of tools. Yet the operator's job is likely to remain substantially, as it is now, responsible and semi-skilled—more interesting than the equivalent jobs on conventional machine-tools and demanding more technical understanding, but requiring no greater technical skill or training.

Example 2: *Automatic looms for weaving textiles*

Based on information provided by Dr. P. Fensham, of the University of Cambridge, who is conducting research into the introduction of automatic looms in a synthetic-fibre plant. (See Appendix V).

The second example of machine-minding, a weaver on automatic looms, lies outside engineering and relates to an occupation that has always been regarded as skilled. The loom, like the machine-tool, has evolved over a long period and the degree of automation has gradually increased, though even the "automatic" loom of today is not fully automatic.

In the automatic loom the spool (or shuttle) is changed without stopping the machine. A magazine (or battery) of spools is loaded by hand and automatically feeds into the loom while it is running. Filling and loading the magazines or batteries is the only new task for the weaver, but he (or she) has considerably less

physical work to do on each loom than formerly and so he can take on many more looms; his maximum may rise to 30 or more. As he is responsible for more and faster looms, his mistakes cost correspondingly more.

The introduction of automatic looms also means that the weaver has less direct influence on the quality of the cloth, since the looms work more smoothly and there are fewer stoppages. He has to examine the looms while they are running to see that no damage is being done, but he has less damage to repair than formerly. He detects faults; the loom-mechanic corrects them and generally maintains the loom in good working condition. The weaver becomes, in fact, more of a machine-minder and less of a skilled craftsman working on the cloth.

In these two examples—the operator on a transfer-line and the weaver on automatic looms—the work of the machine-minder is similar in many ways, though one job is considered semi-skilled and the other skilled. The worker is responsible for more machines than in the past; he does less work on the material itself and does more supervisory work on the machines; and he bears more responsibility in that his mistakes are more costly.

PROCESS-MONITORS

The monitoring of processes usually takes one of three forms, roughly corresponding to stages in the development of automatic control. At the first stage the operator actually manipulates the process by remote control. At the second, he uses a panel of instruments to vary the speed and quality of production, but does not exercise the same manipulative control. At the third, he monitors a group of instruments in order to give warning when clearly-defined limits of error are exceeded. Only at the third stage, where control mechanisms correct errors themselves, does the operator become part of an automatically controlled process. At the first two stages the rate at which the process can run and the efficiency of control may depend on the speed at which he reacts; but that is not so at the third.

Two examples are given here. In the first, a continuous strip-mill in the steel industry, automatic control is only partial, and there are operations of all three types. In the second, an oil refinery, automatic control is developed much further.

Example 3: Continuous strip-mill

Based on information provided by Dr. W. H. Scott, of the University of Liverpool, who is conducting research into technological change and social organization. (See Appendix V).

Figure 14 shows a typical lay-out of plant and lists the main duties of the crew. With the possible exception of four operatives named the operator, the finisher, the speed-operator and the speed-operator's help, members of the hot-mill crew are mainly engaged in working levers and buttons on the basis of instrument readings and/or in accordance with instructions contained in the production-schedules.

The crews of the older steel mills had to handle the sheet at all stages without mechanical devices; but that work demanded skill, dexterity and judgment on the part of experienced craftsmen, as well as physical strength.

Work on the continuous mill is far less exacting physically, and calls for less skill based on experience. Yet operators must be conscientious and reliable, since errors are more costly, partly because bigger quantities of metal are involved in one "rolling" but also because interruptions arising from mistakes halt the entire mill,

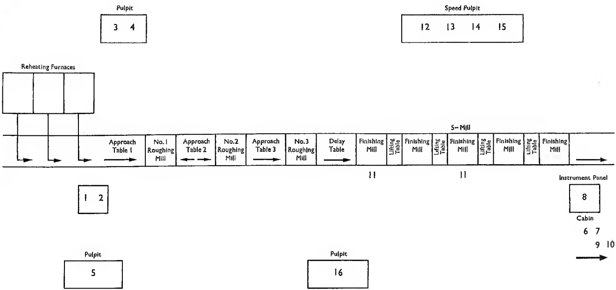

Pulpit
3 4
Speed Pulpit
12 13 14 15
Reheating Furnaces
5-Mill
Approach Table 1
No. 1 Roughing Mill
Approach Table 2
No. 2 Roughing Mill
Approach Table 3
No. 3 Roughing Mill
Delay Table
Finishing Mill
Lifting Table
Finishing Mill
Lifting Table
Finishing Mill
Lifting Table
Finishing Mill
Lifting Table
Finishing Mill
11
11
Instrument Panel
8
Cabin
6 7
9 10
1 2
Pulpit
5
Pulpit
16

Figure 14. Layout of continuous strip-mill (U.K.)

1 *Rougher:* adjusts the gauge of three roughing mills (Nos. 1, 2 and 3 mills) according to a schedule supplied to him. Also adjusts the side-rolls for width.

2 *Rougher's helper.*

3 *Rougher's operator:* operates the rolls, the edging rolls and the approach tables for Nos. 1, 2 and 3 mills.

4 *Helper to rougher's operator:* assists the rougher's operator and operates the water-squirts on Nos. 1, 2 and 3 mills.

5 *Furnace-recorder:* works the tables, bringing the slab up to No. 1 mill. Liaises with the reheating furnace-crew to ensure that slabs from the furnace are of the correct grade of steel. Decides from which furnace the next slab will come. Works from his schedule.

6 *Operator* (another name for roller): is in charge of the whole process from furnace-reheating to coiling. Does nothing but supervision if all is going well. Decides when rolls shall be changed and supervises the change. Rolls may be changed during lulls in order to save time, but otherwise when (9) notifies him of flaws in the sheet.

7 *Operator's helper* (i.e. assistant roller): keeps an eye on temperatures, pressures, speeds, etc. shown on the instrument panel. Assists in changes of roll and in any emergency; otherwise helps the roller with supervisory duties. Changes the gauge on the five finishing mills (5-mill) with (8).

8 *Finisher:* watches the strip coming out of the five mills and ensures that it is running straight by pressing buttons when necessary to tilt the rollers carrying the strip. Changes gauge on 5-mill with (7).

9 *Gauger:* works down by the coiler. Checks the strip or plate for correctness of gauge and width and (if plate) for length. Signals (15) and/or (7) if anything goes wrong.

10 *Gauger's helper.*

11 *Guide-setters:* adjust the width of the guides on the mill. Assist in roll changes.

12 *Speed-operator:* controls the speed of the strip from the delay-table through to the coiler. In practice he operates the last three mills whilst the

13 *Speed-operator's helper:* operates the first two mills.

14 *Looper-operator:* operates the lifting tables between the five mills to break up the scale.

15 *Shear-operator:* works the flying shears. Sets them, when rolling plate, and is notified by (9) if they are incorrectly set. When rolling strip for coil, he judges when to operate shears so as to chop off last few feet of strip.

16 *Delay-table operator:* switches the water-jet on for each slab as it approaches 5-mill. Has temperature-measure of slabs on delay-table and delays slabs if they are too hot to go through 5-mill. All the scheduling for the hot-strip process is checked and watched by a recorder, who is a staff man in the Schedule and Production Department. The recorder ensures that gauge changes etc. are done at the right times. Everything would probably function without him; he is a kind of progress-chaser.

and that is very serious because the ratio of capital to labour is high and the plant is economic only when it runs continuously. Thus although less skill is needed, responsibility is increased.

Automatic control has reached its most advanced form in modern petroleum-refineries and the process-monitoring of the future may resemble what is done there.

Example 4: Petroleum-refinery

Based on information provided by Miss Joan Woodward, South-East Essex Technical College.

Control of the plant is exercised from a central control room (Figure 15). The instruments report the behaviour of the automatic control-mechanisms at various points in the plant. The plant is operated by a team, usually a charge-hand and a panel-man with two or three plant operators under their control. The panel-man has the entire control panel under general and almost continuous observation. He also makes periodic examinations for the purpose of logging process-conditions like temperature, pressure and viscosity. This does not mean that he suffers the strain of continuous and close visual inspection of the instruments. If the control limits are exceeded an alarm system comes automatically into operation and in emergencies action is taken automatically to shut down the plant.

Routine adjustments of the instrument-settings are usually initiated by the charge-hand, or by the panel-man if he is not available. Other members of the operating teams are instructed to do what is necessary. As a rule, there is no qualified technologist or technician on the plant outside normal day hours, but there is one on call for emergencies.

It is difficult to compare the levels of skill required by process-monitors in a refinery with other levels of skill, for example in engineering, because the traditional categories of unskilled, semi-skilled and skilled craftsmen do not exist there. A man may start as a labourer and may rise progressively to the rank of charge-hand as he acquires experience of the plant. His pay is then equivalent to that of a skilled craftsman; but his skill is really knowledge of the plant which he has acquired over a long period. The panel-man, a grade below him, is regarded as semi-skilled. He in turn is promoted from the highest paid grade of operator below him.

COMPUTER-TEAMS

In none of the cases described above—transfer-machine, automatic looms, continuous strip-mill or petroleum-refinery—are the new operative skills beyond the grasp of existing workers. A radical change in skills does arise in offices where a group is created to operate an electronic digital computer on clerical work, but suitable clerks can be trained for some of the new jobs.

Example 5: Electronic digital computer in an office. (Figure 13)

An electronic digital computer engaged on office work is usually operated by a team consisting of three main groups:

(a) *Programming staff*, usually mathematicians and experts in method-study. They look into existing clerical operations and procedure to see which can be transferred to a computer. They also work out programmes for the computer in the form of directions to the operating group.

(b) *Operating group*, comprising those who run the computer, usually on a shift basis, and those who run ancillary equipment which converts the input data into a suitable form for the computer.

(c) *Maintenance technicians*, employed either by the company that operates the computer or by the manufacturer.

Obviously the engineering skills required for the computer cannot be provided by clerks. The same may be substantially true of the skills required in programming, though J. Lyons and Company have found that they can select successful programming staff from people who can think logically but who have not had advanced mathematical training; they take people who did well in algebra at grammar school, and who are practical and creative. Some operators can be drawn from clerks and operators of traditional office machines. One American insurance company recruited an operating group of 19 entirely from its own staff. Most of them were trained on the job.[201]

CHANGES IN OPERATIVE SKILLS

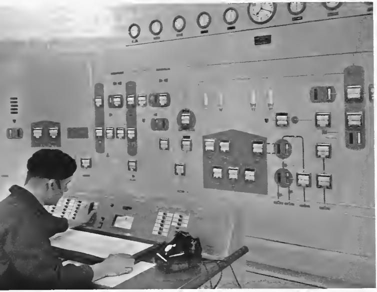
The above examples show clearly that no single definition will cover all operative tasks on automatic processes. The work varies according to the type of industry and to the degree of automation in it. In some cases operative skills are raised but in others they are lowered. For example, in some process-industries the need for subjective judgment by skilled and experienced operators is reduced, whereas the job of the machine-operator in engineering remains semi-skilled but appears to be more responsible and interesting. Despite these very big differences, there is a common trend in skills—towards supervision rather than direct manipulation of the process, and towards skill based on knowledge of plant and equipment rather than manual dexterity or craft-skill.

These changes are sometimes characterized as a switch from "motor" or manual elements to "perceptual" and "conceptual" elements in skill, that is to say to the ability to take in information and the ability to organize or interpret it for action. The above examples give evidence of a trend in this direction but not of a real transformation. At most there is a change of emphasis between the three elements, which are present in all skills.

The perceptual element seems to be most important in partly automatic processes, where the human speed of reaction limits the rate at which the process can run. The operator may be required to take in and act continuously on a heavy load of information, and "perceptual fatigue" may arise. This strain is alleviated in fully automatic processes, however, because the control mechanism takes the corrective action and the operator acts solely as a monitor (see Example 4, page 72). This is one human benefit from fully, as distinct from partly, automatic processes. Yet it is argued that work on fully automatic processes involves no activity for most of the time, but quick and intelligent response in emergencies, and that human beings are not very good at it. This may or may not be so: more knowledge is required.

Whatever the industry, and regardless of whether the process is partly or fully automatic, the trend towards remote control will lead operators to act increasingly on instrument-readings and other visible and audible signals. In the control room of a petroleum-refinery, for example, the control panels have become so complex and so extensive that it is difficult to take in all the changes that the instruments record. Smaller instruments have had to be designed, and the system of control has been

Figure 15. Automatic control in a petroleum refinery (U.K.)
(*a, above*) General view of a control room. (*b, below*) Details of a graphic panel



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presented in the form of a graphic panel (Figure 15) which helps the operator to understand what is going on, improves his efficiency and reduces strain. Thus modern equipment, being complex, needs good design and lay-out, and an effective presentation of information.*

Changes in the perceptual element in skill may not be as significant on fully automatic processes as changes in the conceptual element. Because automatic processes are integrated, few jobs can be done effectively in isolation. The operative may have to correlate his instrument-readings with others; he will sometimes have to interpret a trend of events by reading a group of instruments; and he will need to understand his machine or process well enough to take sensible action in the event of break-down or emergency and to co-operate intelligently with the technical specialists who can put matters right. He does not need a high degree of technical knowledge, but he must have a broad understanding of what is going on. Since he is called on to organize and interpret information, the conceptual aspect of his job may become more important than in the past, even though he works to routine instructions for most of the time.

Alongside changes in skills, automation tends to give the operative greater responsibility, because it increases the scale of damage or of loss of production that his mistakes can cause. The machines are more costly, a great amount of material can be wasted through failure to correct faults promptly, and more production may be lost through stoppages because the whole plant can be halted if a single machine goes wrong. Responsibility in this sense implies not that difficult decisions are taken, but that the operator must be conscientious and reliable.

CONCLUSION

Operators on present-day automatic processes need no advanced technical training but they must learn to understand their machines and processes. They may need more skill or less than formerly, according to the process, but there is rarely a sharp break with existing skills. The evidence suggests that the new operative skills can be acquired through a moderate degree of training on the job.

The new technical and managerial skills—including those of programmers, "systems" engineers, maintenance-craftsmen and more highly trained managers—are not so easily acquired. If they are taken into account, the general level of skill will certainly tend to rise in the sectors of industry affected by automation, especially where routine clerical work is taken over by electronic digital computers. What happens to the level of skill in the working population as a whole will depend on the extent to which automation spreads, and on what happens to skills in those sectors of industry that it does not affect. (The effect of automation could be overshadowed by the influence of other developments, such as the continued spread of traditional techniques of mass-production.) But on the whole it seems that the level will rise, rather than fall.

SATISFACTION FROM WORK

Because automation increases the ratio of skilled managerial and technical personnel to operatives, it is widely assumed that the number of potentially satisfying jobs will

* This need is behind the rapid development of the study known as ergonomics (Gk. ergon - work; nomos - law). Most research so far has been connected with military equipment, but much of it is relevant to industrial equipment too. A good deal of the available information is summarized in Reference (193).

rise accordingly. But that need not be so. Traditional mechanization of processes has also increased the number of managers and technicians, but it has created simultaneously a large number of monotonous jobs. Work on the production-line of a modern mass-producing factory is repetitive, unskilled (though highly specialized), remotely connected with the broad aim of production, and often bereft of intrinsic interest. Its pace is frequently set by the machine and not by the worker. How far does automation change this state of affairs?

PHYSICAL ASPECTS OF WORK

Recent research has produced interesting evidence on the problem of pace-setting by machines. One study, conducted on a motor-car assembly-line, has led to the conclusion that "the mass-production characteristic disliked most by a majority of workers in our sample was mechanized pacing".(203) Other research on the organization of repetitive tasks suggests that constraint on the worker, of which mechanical pace-setting is one aspect, has an important effect on the satisfaction given by work.(197) Again, laboratory experiments at Cambridge University suggest that workers, particularly the older workers, find "time-stress" and "speed-stress" the most difficult conditions of work to bear.(205) This evidence is not conclusive, but it does at least indicate that pace-setting by the machine is an important problem.

The operator on a fully automatic process rarely needs to adapt his speed of working to that of the machine. Usually his work consists of routine checks according to a programme which he or the management has set. Only occasionally is he called to action by the machine—when it breaks down, for instance. But in partly automatic processes the problem of pace-setting remains. One good example concerns the operator who does repetitive work between two automatic machines, which require work to be removed and fed respectively, both at fixed intervals. Another example is the monitoring of processes, where the worker has to close the control-loop and in doing so to act on a continuous flow of signals. In such cases the worker is tied to the process and may suffer boredom and fatigue, especially where the task, though simple and repetitive, calls for constant attention.

The more a process becomes automatic, without actually completing the change, the greater is the likelihood of dissatisfaction due to pace-setting by the machine. But this trend seems to be reversed when processes become fully automatic, since the worker is no longer immediately involved in the chain of operations on the product.

Remote control, whether by electronic or other means, takes the operator one step further from the chain of operations since it removes the need for him to work alongside the machine or process. Thus, automation can improve physical conditions in varying degrees, the benefit being especially great in occupations, like steel-rolling, that were formerly arduous (see pages 70–2).

There is also a decline in the rate of accidents when processes become fully automatic. For example, the Ford Motor Company in the U.S.A. claims that accidents on cylinder-block machining operations, where automation has been extensive, have fallen by 60 per cent since 1950.(194)

INTEREST IN THE JOB

Against these advantages must be set the possible loss of satisfaction from physical activity on the job and from physical contact with materials. These losses may be

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Figure 16. Operator at an automatic extrusion plant (U.K.)

considerable, particularly where much has depended in the past on the judgment of materials by a highly skilled operator. But physical satisfactions have already disappeared from many of the jobs that automation is likely to eliminate and automation will at least provide real substitutes for them. The operator, being something of an onlooker, will often see more of the process than the worker who does routine, repetitive jobs. In general, he will receive a wider range of technical information, because he must understand how his own job fits in with others on the same process. In some cases he obtains a synoptic view of the whole process, either directly or in the form of diagrams. (See Figures 15 and 16). Finally he will help to control an imposing array of machinery—a likely source of pride. All these innovations will probably make his work more interesting than it was before automation.

METHODS OF PAYMENT AND ARRANGEMENT OF HOURS

Payment by piece-rates, based on the output of individual workers, rarely suits work on automatic processes. The rate of output will be decided by managements on technical grounds, and it will be controlled by technicians rather than operatives. Moreover, the contribution of one operative can rarely be isolated from the contributions of others, so payment will tend to reflect the performance of a team or factory rather than that of an individual; and it may be based on criteria other than output, for example machine-utilization. Also new techniques like job-evaluation and merit-rating will probably be more widely used for similar reasons. Whether these changes will increase satisfaction from work is uncertain, for the evidence of research so far does not warrant a definite conclusion as to how piece-rates affect satisfaction. But it is known that piece-rates can be a source of grievance and dispute, and automation may confer some benefit by narrowing their scope.

Since automation will require more shift-working, with periodic shutting down of plant for inspection and maintenance, it is bound to stimulate fresh thinking about the arrangement of working hours. The best possible arrangement must depend on several factors; what period of monitoring duty is compatible with efficiency, health and safety; what are the technical requirements for continuous operation and maintenance of plant; and what effects shift-working has on domestic and community life. These questions clearly affect the satisfaction of the worker with his job. Although they cannot be answered firmly, there has been much research into the effect of working hours on the health and efficiency of the individual, and some research into problems like shift-rotation.[192, 207] The effects of shift-work on domestic and community life are also being studied. For example, the preliminary results of research conducted by the University of Liverpool among women whose husbands have recently begun continuous shift-working suggest that, although workers see an important disadvantage in the loss of a week-end for social activities, they have no serious difficulty in adapting domestic arrangements for shift-work. (See Appendix V).

OPPORTUNITIES FOR PROMOTION

More needs to be known about how opportunities for promotion vary from industry to industry before the effect of technical advance on them can be seen with any certainty. But it does seem that the effect will be adverse if the existing gap in technical skill and knowledge between operatives and supervisors on the one hand, and qualified managers and technicians on the other, becomes too great to be bridged by

experience gained on the job. Manual workers do rise to managerial jobs surprisingly often. A recent study by the Acton Society Trust among 50 companies, each employing 10 000 or more persons, showed that 40 per cent of the 3300 managers in the sample had been in the same company all their lives. Nearly 20 per cent went to elementary school only and about the same number reached a university. Almost 80 per cent had no professional qualification.[200] (See first footnote on page 106).

Progress with automation will tend to call for educational qualifications in a greater proportion of jobs, and so will tend to make it more difficult to advance through experience gained on the job. In some industries even supervisors may require qualifications that can be acquired only at educational institutes. It seems, therefore, to be increasingly important for industrial firms to find the potential managers and technicians in their ranks and give them the necessary training for promotion, either within or outside the firm, so keeping the line of advance open.

THE WORKING GROUP

The expansion of repetitive jobs in mass-production has laid emphasis on the so-called "social satisfaction" that may compensate for the lack of satisfaction from the job itself. Team-work is an important source of social satisfaction but, as has been shown in research by the Tavistock Institute of Human Relations,[206] the nature of team-work changes along with the technical basis of production. Is there a typical form of working group on automatic processes, and if so is it likely to provide more satisfaction or less than before?

Operatives on automatic processes are often spread thinly over a big area, and each of them covers an extensive part of the plant and so may become isolated, though not where control is centralized. Yet they can obtain a new social satisfaction from technical co-operation with maintenance men and members of technical management. The three groups have a clear and important objective in common—to keep the machine-line or process running—and this may prove more satisfying than membership of an operative team. Discipline on automatic processes is exercised more through the technical requirements of the plant than through differences in status between employees. All told, the related functions of operatives, maintenance men and supervising technicians seem to provide a basis of team-work on automatic processes and may help to improve human relations.

CHAPTER VI

Conclusions

THE MAIN PURPOSE of this Report is to put automation in perspective and to discuss its probable future impact on industry. The picture is necessarily incomplete, but it leaves no room for doubt that automation is extremely important, if not exactly new, and that it comprises a continuous chain of technical developments, which will extend well into the future.

Some technical trends can be foreseen fairly clearly. The production, handling and assembly of components will be further mechanized and transfer-machines will be more widely used in the mass-production of engineering components. Automatic control of processes, already far advanced in great industries like petroleum and chemicals, will continue to make progress. Electronic computers will help to solve problems of management, at first by doing routine clerical work of various kinds and later by controlling processes and machinery and by achieving the integration of control that must precede the establishment of an automatic factory.

It seems clear that during the next decade or two the impact of automation will be heavy and extensive, even though many industries will probably remain little affected. The benefits will not be confined to large firms, though they are as a rule favourably placed. Many small firms may find their factories suited to automatic processes on both economic and technical grounds.

As experience of automation grows, its future importance to the nation becomes increasingly apparent. Like other advances in technique it will increase efficiency and should, therefore, reduce costs. It will be of special importance to a country so dependent on overseas trade as the United Kingdom, because it will increase production and help to keep prices competitive. Automation can also increase living standards, though it is difficult to forecast how the gains will be divided. On the social side it seems likely to increase the national requirement for skill and to cut out a number of dull, heavy or fatiguing jobs. In addition, it will almost certainly change the character of skills and of team-work in ways that workers may appreciate.

At the same time automation is likely to create serious problems, most of them common to all forms of technical advance, and industry must solve them if automatic processes are to spread widely without the social and economic dislocation that marred the early history of the Industrial Revolution. Like all innovations it entails risks and at each stage of development sufficient firms must have the resolution and imagination to take chances and act on informed guesses, where necessary. As experience is gained it should be published, so as to demonstrate the economic advantages of automation to more sceptical or conservative managements. There is an urgent and growing need for comparative information on the capital and running costs of automatic and conventional equipment.

Progress with automation will also depend on how readily individual firms can raise capital for development. In terms of national accounting there is no likelihood of capital being short and large firms should be able to save or raise all they need, especially in industries with expanding output. But some small firms may have difficulty in getting money from the usual sources. Scarcity of fuel, certain materials and some types of machinery may be widely felt.

The most important brake on progress will almost certainly be the existing and prospective shortage of technologists and managers. Automation both increases the need for them and requires them to have more qualifications and skills. It implies an expansion of training facilities within the educational system and a reassessment of the needs they serve (for, so far as technology is concerned, the needs cut across the existing boundaries of professional training). Automation implies also that firms should seek to train and promote the potential managers and technicians of all grades who are still in the ranks. Finally, it emphasizes the importance of co-operation among technical specialists, and between them and managers on the one hand and maintenance-craftsmen and operatives on the other. Qualities like versatility, adaptability and capacity for understanding other viewpoints look like being increasingly valued in managers and professional staff.

So far as factory management is concerned automation greatly increases the need for planning in order to minimize the technical inflexibility of highly integrated plant, to establish preventive maintenance and to provide for continuous running of machinery. Techniques of management that are now needed to handle labour will give ground to new techniques that suit automatic processes, for instance in the systematic study of operations, the use of computers and the control of costs.

Finally, the transition to automation will be greatly eased if due attention is given to the needs, feelings and problems of the workers concerned, and if the trade unions are consulted in advance of each step. At present interest tends to be focussed on the possibility of automation causing unemployment, but this is unlikely to be a serious problem if its introduction is not too rapid (and the shortage of technologists will probably make sure of that), if firms keep redundancies to a minimum by adhering to good managerial practice, and if a state of full employment continues so that redundant workers can be quickly re-absorbed. It is important, however, that firms should plan their manpower requirements well ahead in terms of numbers, skills and formal qualifications and so avoid, wherever possible, the risk of having too much or too little labour.

Changes in operative skills will also be made more smoothly if they are carefully planned, if proper provision is made for training on the job, and if workers are consulted and kept well informed of likely developments. There may be difficulties in acquiring or adapting skills, especially among the older workers; in persuading workers to accept shift-work and so make continuous running possible; and in maintaining workers' interest in the job without the traditional operative teams affording regular social contact. But none of these difficulties is unsurmountable, given wise management.

The above is an extremely simplified précis of the conclusions that can be drawn from this Report. They need, of course, to be qualified by reference to the many variable factors in the future course of automation. Conditions and experience will differ from one industry, plant, process, or management to another; above all the pace of development will be a crucial, though still imponderable factor. Rapid progress may make adaptation difficult, but slow progress should be easy to contain—though it may be less than is economically desirable.

In conclusion, one truth stands out from this Report—the imperfections of present knowledge of the economic and social aspects of automation, when compared with knowledge of the technical possibilities. It becomes more vital each year to extend knowledge of these aspects by research and exchange of experience, especially by case-histories of firms with automatic processes. A list of possible subjects for research is given in Appendix V on page 104.

ANALOGUE AND DIGITAL COMPUTERS

An Explanatory Note

AN ANALOGUE COMPUTER is a device that simulates the behaviour of another system, usually a physical system, in all its states. A very simple and widely used analogue computer is the slide-rule on which distances are equivalent to logarithms of numbers.

The devices currently known as analogue computers are assemblies of electronic or electrical circuits, the behaviour of which is analogous to that of, say, a mechanical system. This analogy is possible because a large number of physical and mechanical systems can be described by mathematical relationships of some kind, usually differential equations. The analogue computer can be made to obey the same kind of equations.

For example, an electrical system (the analogue computer) and a physical system (flow of heat through a lagged pipe) can be made to obey the same mathematical rules. If the electrical system incorporates the correct components, both constant and variable, its output (in terms of voltage perhaps) can represent the flow of heat through the physical system and a recording of this output can be interpreted as the solution of the problem of heat-flow. The user of the computer must find out enough about the problem that is to be solved to express it in terms of an equation. He must also know enough about the analogue machine to design a circuit that will obey the same equation or a close approximation of it. The simulation must be made reasonably accurate over the whole range of the problem.

The digital computer differs from the analogue computer in that it deals with numbers and not physical quantities. The simplest digital computer is the human hand, from which the decimal system is derived. The first man-made digital computer was probably the abacus, which is still used in many countries.

The evolution of the adding machine has culminated in electronic digital computers in which electrical signals are used as the operative discrete signals. The modern radio valve can be in either of two states—conducting or non-conducting—and so it will either allow an electrical signal to pass or prevent it from passing. Because of this property and for other reasons, it is convenient to base electronic computers on the binary scale, and not on the more familiar decimal scale.

When an ordinary desk calculating machine is used, the operator controls the sequence of operations. He supplies the input data and records the results. Also he may have to provide additional information from tables and other sources during the calculation. In the case of electronic computers, working at extremely high speeds, the human operators are replaced by automatic devices. It is necessary, however, to provide a store to hold both the numbers that are fed into the computer and the operating instructions. The basic sections of the digital computer are therefore:

Input: receives the "raw data" and instructions from external sources and converts them into a suitable form for the computer to work on.

Store: memorizes numbers and instructions.

Calculator: does mathematical operations.

Control: initiates and follows the sequence of operations.

Output: presents the results of the calculations in an acceptable form.

APPENDIX II

SOME COSTING AND OPERATIONAL STUDIES OF AUTOMATIC EQUIPMENT ALREADY IN USE

IT IS DIFFICULT to obtain adequate information about the cost and operation of automatic equipment already in use, because authoritative studies are few and vary greatly in depth and accuracy. Some are little more than broad estimates of expenditure in particular categories, and the underlying assumptions are not always made known. Even where the results show large savings in manpower and other costs, there is not necessarily a conclusive argument in favour of automation. The cost of installing, running and re-tooling plant needs to be known before the financial advantages and disadvantages of automation can be properly assessed. But the following figures give a little idea of how much automatic equipment costs (compared with conventional equipment where possible) in a few firms that have introduced it.

AUTOMATIC CONTROL OF CATALYTIC CRACKING (U.K.)[48]

The capital outlay on instruments for the automatic control of a medium-sized catalytic cracking plant (processing 10 000 barrels a day) is estimated to be 5–10 per cent of the cost of the entire plant. The capital cost in one plant, owned by the British Petroleum Company, is set out in Table V, while Table VI shows the annual costs of operation and maintenance. Since automatic equipment is indispensable to the control of a catalytic cracking plant, its cost cannot be compared with that of "standard" or "conventional" equipment.

Table V: Total investment on instrumentation for a catalytic cracking unit processing 10 000 barrels a day

	£
Material cost of instruments and accessories	43 300
Material cost of piping and wiring materials	6 000
Material cost of air compressors and driers	1 750
Labour cost of installation	4 870
Total	£55 920

Table VI: Annual operating and maintenance costs of instrumentation for a catalytic cracking unit processing 10 000 barrels a day

	£
Instrument air	900
Steam	135
Power	95
Parts replacement	575
Accessories (charts, ink)	275
Man hours (21 796 on average)	7 500
Depreciation (10 per cent of capital cost of installations)	4 330
Total	£13 810

Table VII: Costs per hour of operation; 13 station transfer-machines compared with equivalent standard machines

	Transfer Machine BMA 20266	*Existing Machines: March 1955 Prices*													Total
		6877	6879	7822	9859	9860	9519	9974	10644	11616	13219	13404	13555	13840	
Capital cost	£25 903	£4000	£5500	£800	£3500	£3500	£5000	£800	£4000	£700	£1000	£600	£1000	£450	£30 850
Date purchased	1953														
Floor area sq. ft	390	50	117	15	35	35	81	15	72	11	18	18	18	15	500
Total h.p. of motors	90	12	38	4	7	7	12	4	10	5	8	10	5	3	127
J=interest at 5%	1295	200	275	40	175	175	250	40	200	35	50	30	50	22	1542
K=Depreciation at 12½%	3238	500	687	100	437	437	625	100	500	87	125	75	125	51	3849
L=Insurance at 5%	65	10	14	2	9	9	12	2	10	2	2	1	2	1	38
M=Repairs at 5% up to 2 years	1295	200	275	40	175	175	250	40	200	35	50	30	50	22	1542
N=Indirect material at 2%	518	80	110	16	70	70	100	16	80	14	20	12	20	9	617
Q=Rental at 15/– per sq. ft	292	37	88	11	26	26	60	11	54	8	13	13	13	11	371
R=Power at 1d. per h.p. hour working at 240 days at 8½ hours	765	102	323	34	59	59	102	34	85	42	60	85	42	42	1069
Estimated cost per hour of machine $=\frac{J+K+L+M+N+Q+R \times 240}{240 \times 8 \cdot 5}$	879d.	133d.	209d.	28d.	112d.	112d.	164d.	28d.	113d.	26d.	37d.	29d.	35d.	19d.	1065d.

Cost per hour of machine-operation (transfer-machine) = 879d. = £3 13*s*. 3*d*.

Cost per hour of machine-operation (existing machine, new plant) = 1065d. = £4 8*s*. 9*d*.

Direct labour cost per hour (transfer-machine) = 132*d*. = 11*s*. at output of 3000 a week

Direct labour cost per hour (standard machine) = 686*d*. = £2 17*s*. 2*d*. at output of 2500 a week

TRANSFER-MACHINES (U.K.)[38]

Table VII shows the capital cost, the cost per hour of machine-operation and the direct hourly labour costs of a 13-station transfer-machine used by the Austin Motor Company for making cylinder-blocks. The costs per hour of operation of this machine are compared with those of equivalent standard machines. The capital cost of the transfer-machine is £25 903 against £30 850 for the standard machines, a saving of 16 per cent. There is also a saving on floor space, as the transfer-machine takes up 390 sq. ft, the conventional machines 500 sq. ft. The factors that determine the cost per hour of machine-operation are power, interest on capital, depreciation, insurance, repairs, replacements and rent of floor space.

The sum of these figures, divided by the number of working hours in a year, gives the cost per hour of machine-operation—£3 13s. 3d. for the transfer-machine and £4 8s. 9d. for the other machines, calculated on the same basis.

Two men are needed to operate the transfer-machine, one loading and one unloading. The labour cost per hour is 11s. od. compared with £2 17s. 2d. on the standard machines. The transfer-machine produces 3000 components a week, the standard machines 2500.

MANUFACTURE OF AIR FRAME COMPONENTS (U.S.A.)[19]

In a case study carried out jointly by the Massachusetts Institute of Technology and a manufacturer of air frames, 33 essential components for aircraft were manufactured in three different ways: by a tracer-controlled milling machine, by forging and finish-machining, and by a tape-controlled milling machine. In the last-named method the Institute used its own machine. The results are outlined in Table VIII.

Apparently it did not pay to produce as few as 33 pieces by the tape-controlled milling method. The cost of making a model for the tracer machine to copy was only \$500, but the cost of programming the tape-controlled machine was \$1500. It took three weeks from receipt of blueprint, to prepare the tracer machine for work, and two months to prepare the tape-controlled machine. The latter would produce at a much reduced cost per unit of output over a much longer production-run, as the machine time per piece was only one-third of the time taken by a tracer machine; but neither would compare with forging in really large-scale productions.

Table VIII: Comparative production costs for an aircraft fitting
(Size 8×8×5 in.; 33 pieces)

	Tracer Method	Tape-controlled Milling Method	Forging Die Method
Make-up cost			
Model, die and template cost	\$500		\$10,000
Programming cost (500 m-hour)		\$1,500	
Machine time			
Set-up per run		12 hours	
Machine time per piece, floor to floor	18 hours	6 hours	1½ hours
Hand-finishing, per piece	3 hours	3 hours	
Elapsed time			
Blueprint to machine set-up	3 weeks	2 months	4–6 months

ELECTRONIC COMPUTER (U.S.A.)[201]

The ABC Life Insurance Co., U.S.A., made substantial economies in office organization by installing an electronic computer to process information on approximately 850 000 policies a month. The new method reduced the number of punched-card machines from 125 to 21, and the annual cost of machine rentals from $235 000 to $19 000. Personnel was reduced from 198 to 85 and the cost of wages fell accordingly. These savings were partially offset by the amortization charge on the computer, the regular fees for maintenance paid to its manufacturer, and the cost of down-time (about 4 per cent of working time) due to mechanical failures.

Although the initial cost of the computer was over $1 million, the company expect to recoup its investment in about four years.

ELECTRONIC COMPUTER (U.K.)

How many clerks a given computer can replace depends largely on the type of work being done. LEO, the computer of J. Lyons & Company, if engaged on pay-rolls for 80 hours a week, can save the work of more than 600 full-time clerks. Its use would, however, be economically justified on a much smaller saving. To take a hypothetical instance, if the capital cost of a computer is put at £100 000 and is depreciated over 10 years, and if the running cost is £15 000 a year, the total cost is £25 000 a year, which can be recovered by a saving of 50 clerks at a rate of £10 a week. Thus a computer may be justified even though the expected saving is not more than 50 clerks.

"PROJECT TINKERTOY" (U.S.A.)[120]

The American Navy Bureau of Aeronautics has sponsored research, under the code name "Project Tinkertoy", into ways of producing electronic equipment with parts made by printing circuits on standard wafer-modules. These wafers can be mass-produced and mechanically assembled into many kinds of equipment. But the study was limited to the cost of producing one kind of equipment—intermediate frequency amplifiers—which were to be assembled from five-wafer modules and which were actually produced, partly by hand, in a small pilot plant, where costs had to be deduced to a large extent. The estimated costs of three different methods—(i) conventional, (ii) Tinkertoy hand and (iii) Tinkertoy machine—are given in Table IX. The third method reduced by 44 per cent the cost of production by conventional methods, but the required output of amplifiers was not given.

Table IX: Comparative cost of producing an intermediate frequency amplifier by alternative methods

Method	Materials	Direct Labour	Overheads	Totals
	$	$	$	$
Conventional	35·85	5·60	5·44	46·89
"Tinkertoy hand	20·56	5·99	2·27	28·82
"Tinkertoy" machine	20·56	2·83	2·86	26·25

APPENDIX III

TRAINING COURSES RELEVANT TO AUTOMATION

THE FOLLOWING information relates to courses in higher technology that were available in Great Britain during 1955–6 and were directly concerned with one or more aspects of automation. They were mainly part-time and special courses that offered facilities for students qualified and experienced in one of the fields to which automation can be usefully applied. Some of the courses were not very relevant to automation, but they have been included so as to make the list as comprehensive as possible, though it is by no means complete.

AUTOMATIC CONTROL: GENERAL COURSES

Birkenhead Technical College	Course on electronics and automation lasting twenty to twenty-four weeks. The course covers basic electronics, basic measuring systems, sensing devices, actuating devices, process-control and automation.
Bolton Technical College	A course of lectures (Winter and Spring terms), on systems of automatic control, servo-mechanisms and automation; covering principles, applications and implications of automation.
University of Cambridge: Department of Engineering	Residential post-graduate course on control engineering; commencing October, 1955, and lasting about one year.
Hatfield Technical College	Ten meetings, commencing January, 1956, on automation.
Loughborough College of Technology	Two weeks' full-time course, September, 1955, on basic control principles.
National College of Rubber Technology	Six meetings, commencing February, 1956, on automation in the rubber and allied industries.
Rotherham Technical College	An eight months' course, commencing September, 1955, on industrial control systems.
Woolwich Polytechnic	A series of eight lectures and discussions, November, 1955–March, 1956, on: fundamentals of automatic process-control; automation in the office; automatic linking and transfer devices; automation of machine-tools; automatic machine and process-control; automatic processing in the petroleum industry; a general assessment of the economics of automatic processes and control; automation in the motor car industry; automatic control of thermal and mechanical processes as exemplified by the steel industry.

AUTOMATIC CONTROL IN MECHANICAL AND PRODUCTION ENGINEERING

Coventry Technical College	Eight weekly meetings, October to December, 1955, on the applications of automatic control in industry with particular reference to machine tools and to related aspects like design, operation, training and finance.
Leeds College of Technology	Eight weekly meetings, Spring, 1955, on electronics in mechanical engineering.
Mid-Essex Technical College and School of Art, Chelmsford	It is intended to start a new course on electronics for mechanical and production engineers if there are sufficient enrolments. The course is specially designed for mechanical engineers concerned with the electronic control of machine-tools and similar mechanisms.

COMPUTERS

Acton Technical College	Ten meetings, commencing January, 1956, on the logical design of digital computers using packaged units.
University of Cambridge	Eleven-day course on programme design for automatic digital computing machines. September, 1955. (Likely to be repeated in 1956.)
Sir John Cass College, London	Twenty meetings on methods of numerical analysis, including programming of electronic computing machines.
Cornwall Technical College: Department of Science and Mathematics	Six lectures from January, 1956, on modern electronic counting techniques, including their application to batching machines for small components, precision movement of machine-platforms, radio-active assaying, and digital computers.
Coventry Technical College	Fourteen meetings, commencing June, 1955, on digital computing circuits.
Coventry Technical College	Ten weekly lectures, commencing October, 1955, on commercial applications of digital computers.
Liverpool College of Technology: Department of Mathematics and Physics	Eleven lectures commencing October, 1955, on the application of digital computers to accountancy, costing and managerial control.
Northampton Polytechnic: Electrical Engineering Department	Ten meetings on digital and analogue computing: theory and scope in research and development.
Northampton Polytechnic: Electrical Engineering Department	Ten meetings on digital computers used as tools for research.

Northampton Polytechnic: Electrical Engineering Department	Ten meetings on digital and analogue computing: description and basic principles of computers with applications. This course is intended for actuaries, accountants, statisticians and administrative staff.
Northern Polytechnic	Twelve meetings from September, 1955, on analogue computing and twelve meetings, also from September, 1955, on digital computing.
Residential Centre for Further Education (County Education Committee), Dillington House, Ilminster, Somerset	Short residential course on digital computers planned for 1956.

Some firms are organizing courses for potential users of their computers. For example, Ferranti have established a training school in London which holds courses of one or two weeks' duration covering all aspects of computer operations. Elliot Bros. (London) offer at intervals a three weeks' course on electronic computing, which covers among other things the application of computers to business organization and to actual problems brought foward by members of the course.

INSTRUMENTATION

Battersea Polytechnic: Electrical Engineering Department	Eleven meetings on the industrial measurement of temperature, pressure, level and flow, emphasizing methods of measurement that are suitable in closed-loop systems of control.
Bradford Technical College	Eight weekly lectures, commencing on 2nd May, 1956, on instrumentation analysis.
Brighton Technical College: Mechanical Engineering Department	Twelve meetings on the practice of plant engineering, including instrumentation and automatic control.
Hendon Technical College	Twelve meetings, commencing January, 1956, on electronics including pulse techniques and applications to servo-mechanisms.
Northampton Polytechnic: Instrument Engineering Section	Twenty meetings on industrial methods and instruments for the measurement of pressure, specific gravity, flow, temperature and systems for the transmission of information.
Sheffield College of Commerce and Technology	Ten weekly lectures commencing October, 1955, on instrumentation in industrial and research laboratories.
Sheffield College of Commerce and Technology	Ten weekly lectures commencing January, 1956, on electronics applied to industrial control and instrumentation.

SERVO-MECHANISMS

Barrow Technical College and School of Art	Twenty meetings on servo-mechanisms and electronic control.
Battersea Polytechnic: Department of Electrical Engineering	Part-time post-graduate course of 24 meetings on the principles of linear servo-mechanisms: (1) theoretical basis and laboratory measurements, (2) methods for industrial measurement and closed-loop control.
Birmingham College of Technology	Ten weekly lectures commencing January, 1956, on the basic theory of automatic control and automatic control-circuits.
Birmingham College of Technology	Eight weekly lectures commencing October, 1955, on the latest developments in the electronic control and supervision of industrial processes.
University of Birmingham: Department of Electrical Engineering	Residential post-graduate course, September, 1955, giving an introduction to automatic control.
Coventry Technical College	Eight weekly meetings, January–March, 1956, on the design and operation of hydraulic, electric and pneumatic mechanisms and their application in the machine tool, aeronautical and motor-vehicle fields.
Gloucester Technical College: Science Department	Twenty-four meetings commencing October, 1955, on servo-mechanisms.
Hatfield Technical College: Technical and Design Engineering Department	Thirty meetings on systems of automatic control.
Manchester College of Technology: Mechanical Engineering Department	From time to time "ad hoc" courses are provided at post-graduate level; they have included series on hydraulic control techniques and on servo-mechanisms. Similar courses are under consideration at present.
Medway College of Technology	Twenty-five meetings on applied electronics, including electronic computing, process-control, control of motor-speeds.
Northampton Polytechnic: Electrical Engineering Department	Twenty meetings on the fundamental principles of control mechanisms, in which the behaviour is represented by the coefficients of differential equations.
Northampton Polytechnic: Electrical Engineering Department	A course of twenty meetings which continues the locus diagram of response and introduces logarithmic response graphs and contour charts; the analysis of special servo-elements is developed.
Nottingham and District Technical College	Eight or twelve lectures, commencing January, 1956, on servo-mechanisms.

Rugby College of Technology and Arts	Twenty weekly evening lectures commencing October, 1955, on electrical circuit analysis and closed-loop systems of control.
Southall Technical College	Eighteen lectures on the theory of servo-mechanisms.
Southall Technical College	A course of six meetings on experimental servo-mechanisms, which is intended initially for those students who have previously taken the above theoretical course.
Wolverhampton and Staffordshire Technical College	Ten weekly lectures commencing October, 1955 on electrical servo-mechanisms.

Besides formal lecture courses, there are facilities for post-graduate training in research techniques at a number of universities and university colleges, for instance: the Universities of Birmingham, Durham and Edinburgh; the University Colleges of North Wales (Bangor) and Southampton; the Imperial College of Science and Technology (University of London); and the Heriot Watt College, Glasgow.

APPENDIX IV

REFERENCES

THE FOLLOWING references are selected from an extensive bibliography on automation which is being prepared by the Department of Scientific and Industrial Research. They are in no way comprehensive, but they should be a satisfactory guide to further study of topics discussed in this Report.

This list includes a number of Russian papers, some of which are available translated into English. These are indicated. Enquiries about the possibility of having others translated should be addressed to the Department of Scientific and Industrial Research, Charles House, 5–11 Regent Street, London S.W.1.

A. BIBLIOGRAPHIES

1 List of publications on automatic regulation and related subjects (Spisok otechestvennoi literatury po avtomaticheskomu regulirovaniyu i smezhnym voprosa)
(*a*) for 1949 and 1950 *Avtomat. Telemekh., Moscow*, 1951, 12(3), 253–62
(*b*) for 1951 *Avtomat. Telemekh., Moscow*, 1952, 13(2), 217–24
(*c*) for 1954 *Avtomat. Telemekh., Moscow*, 1955, 16(2), 219–24, (3), 317–20
(*Copies of translations of* (*b*), (*price* 16*s.* *od.*) *and* (*c*), (*price* £2) *can be purchased from DSIR Technical Information and Documents Unit*, 15 *Regent St., London S.W.*1, *on quoting references CTS* 46 *for*(*b*) *and CTS* 152 *for* (*c*)

2 Automation (Bibliography). *Bulletin of the Business Information Bureau*, Cleveland Public Library, July–December, 1953, 24(4) (Entire issue)

3 Business applications of electronic machines: an annotated bibliography. Controllership Foundation Incorporated, New York, 1955

4 CHAPIN, N. Publications for business on automatic computers: a basic listing. *Computers and Automation*, September, 1955, 4(9), 13–16

5 GIRSHIN, P. I. Recommended reading list on the subject of the automatic recording and control of technical processes (Rekomendatelnyi spisok literatury po avtomatike ucheta i kontrolya tekhnologicheskikh protsessov). *Tekstilnaya Promyshlennost*, 1954, 14(7), 54

B. GENERAL

6 On the work of the Institute of Automatics and Telemechanics of the Academy of Science (Khronika v Institute Avtomatiki i Telemekhaniki Akademii Nauk SSSR. Vtoroi god raboty seminara po teorii avtomaticheskogo regulirovaniya). *Avtomat. Telemekh., Moscow*, 1949, 10(4), 325

7 Factory of the future. *Fact. Mgmt*, April, 1952, **110**(4) (Entire issue)

8 The automatic factory—what does it mean? (Report of the Conference held at Margate, 16th to 19th June, 1955). Institution of Production Engineers, London, 1955

9 Automation. *Iron Age*, October 21, 1954, 174, 213–36

10 Automation. *Metalworking Production*, June 10, 1955, **99**(23) (Entire issue)

11 Automatic factories. *Time*, January 18, 1954, 80–1

12 BENDINEK, R. The age of the thinking robot and what it will mean to us. *The Reporter*, 1955, **12**(7), 12–18

13 BRIGHT, R. J. How to evaluate automation. *Harvard Business Review*, July, 1955, 33, 101–11

14 DIEBOLD, J. Automation: the advent of the automatic factory. Van Nostrand, New York, 1952. 181 pp.

15 EGAN, E. J. Two approaches to automation. *Iron Age*, July 1, 1954, 173(1), 93

16 HARDER, D. S. and DAVIS, D. J. Problems of the automatic factory. *Automot. Industr., N.Y.*, April 15, 1953, 40–1, 110, 114, 116, 118, 120, 122

17 HARDER, D. S. and DAVIS, D. J. The automatic factory? (Paper presented before the National Production Meeting of the Society of Automotive Engineers, Cleveland, March 26, 1953). *Tooling and Production*, May, 1953, **8**, 32–3, 96–101, 132

18 JACOBY, C. J. Analysis of developments in automation. *Mech. Engng, N.Y.*, October, 1952, **74**, 810–11, 828

19 JUNE, ST. A. *et al.* The automatic factory—a critical examination. *Instruments and Automation*, September, 1954, 27(9), 1476–8 (Continued in the October–December, 1954, January–February, 1955 issues)

20 KRASIVSKI, S. P. Automatic operation of production processes (Ob avtomatizatsii proizvodstvennykh protsessov). *Avtomat. Telemekh., Moscow*, 1950, **11**(4), 213–25

21 LOCKSPEISER, SIR BEN. Science and our industrial future (Address to the Parliamentary and Scientific Committee). *Research, Lond.*, June, 1954, 7(6), 236–41

22 OSBORN, D. G. Geographical features of the automation of industry (*Research Paper No.* 30). University of Chicago, Department of Geography, August, 1953. 106 pp.

23 RUBINFIEN, D. Guideposts to further automation. *Plant Administration (Toronto)*, September, 1954, 14(9), 126, 131–4

24 SCOTT, D. Russians apply automation to 20 year old machines. *Amer. Mach., N.Y.*, October 11, 1954, **98**, 164–8

25 SHALLENGBERGER, F. K. The pushbutton factory. *Engng J. Can.*, November, 1952, 35, 1194–8

26 TUSTIN, A. Feedback. *Sci. Amer.*, September, 1952, 187(3), 48–55

27 WALLACE, D. A. Automation. *Advanced Mgmt*, January, 1953, 18(1), 52

C. ECONOMICS AND MANAGEMENT

28 Central Statistical Office. National income and expenditure, 1955. H.M. Stationery Office, London, 1955

29 Central Statistical Office. *Monthly Digest of Statistics*. H.M. Stationery Office, London

30 An automatic foundry. *Engineering, Lond.*, November, 1954, **178**(4634), 647

31 Ministry of Fuel and Power. *Statistical Digest*, 1953. H.M. Stationery Office, London, 1954

32 The mobility of electronic technicians, 1940–52: the work experience, training and personal characteristics of workers in a new skilled operation (*Bulletin No.* 1150). U.S. Department of Labor, Bureau of Labor Statistics, 1954. U.S. Government Printing Office, Washington, D.C.

33 BEZIER, P. Automation—its implications for management (Paper presented to the B.I.M. Management Conference, Torquay, October, 1954). *Machinist*, November 12, 1954, 98(46), 2001–7

34 BROÏDA, V., DEMARLES, F. and VIVIE, J. La situation actuelle de l'enseignement de l'automatisme en France et à l'étranger. *Mesures et Controle Industriel*, March, 1955, 20(214), 171–8

35 BROWN, B. C. Industrial production in 1935 and 1948. London and Cambridge Economic Service, London, 1954

36 DRUCKER, P. F. America's next twenty years. *Harper's Magazine*, March–June, 1955 (Reprint)

37 GORDON, C. and EASTERFIELD, T. E. Effects of simplification on productivity. (Document DT/C/ST/734, pp. 29 and 37). O.E.E.C., Paris, 1952. (*Loan copy available from D.S.I.R. Technical Information and Documents Unit*, 15 *Regent Street, London, S.W.*1)

38 GRIFFITHS, F. and HOLBECHE, H. W. Automatic transfer machines. *Process Control and Automation*, March, 1955, 2(3), 81–91; April, 1955, 2(4), 125–9

39 HURNI, M. L. Increasing the opportunities for automaticity. *Mech. Engng, N.Y.*, July, 1954, 76(7), 577–81

40 HURNI, M. L. Decision making in the age of automation. *Harvard Business Review*, September–October, 1955, 33(5), 49–58

41 KNIGHT, C. E. Management with automatic production. *Mech. Engng, N.Y.*, April, 1954, 76(4), 317–20, 355

42 MCDOUGALL, J. How Ford organizes automation programs. *Machinist*, March 7, 1953, 97, 386–7

43 MATTHEW, T. U. The engineer and the automatic factory—a challenge to the University. Institution of Production Engineers. Report of the Conference held at Margate, 16th to 19th June, 1955, 114–21

44 PETERS, A. Pushbutton control cuts production costs (Boulton & Paul, Norwich). *Business*, July, 1954, 84(7), 74–7

45 SUMMERFIELD, J. Capital savings through automatic control. *Management Review*, November, 1954, 43, 710–11

46 SWANN, B. B. Electronic computation: its uses and implications for management. *The Manager*, August, 1955, 23(8), 595–601

47 VLADZIEVSKII, A. P. Estimating labour capacity in setting up automatic production lines (Otsenka trudoemkosti nastroiki avtomaticheskikh linii). *Stanki i Instrument, Moscow*, December, 1951, 22(12), 3–5, 9

48 WALLIS, S. W. J. The economics of process control. *Trans. Instn chem. Engrs, Lond.*, 1955, 33(3), 218–22

D. THE ENGINEERING INDUSTRIES

GENERAL

49 Push button turning by new electronic copying lathe. *British Communications and Electronics*, October, 1954, 1(1), 68

50 AMBER, G. H. Automatic dull drill detection. *Automation*, October, 1955, 2(10), 53–63

51 BOOSEY, F. R. Automatic size control. *Instrum. Pract.*, November, 1955, 9(11), 1067–9

52 CROSS, R. E. Automation eyes the future. *Steel*, January 25, 1954, 134, 92–4

53 ERPSHER, YU. B. On the question of selecting cutting regimes on automatic machine lines (K boprosu o vybore rezhimov pezaniya na avtomaticheskikh stanochnikh liniyakh). *Stanki i Instrument, Moscow*, 1950, 21(12), 12–14

54 FERNEY, L. A. They have also been working on transfer machines in Russia. *Machinist*, October 6, 1951, 95, 1497–1502

55 HUNT, J. A. and JAY, J. B. Automatic linking devices. Institution of Production Engineers. Report of the Conference held at Margate, 16th to 19th June, 1955, 160–179

56 LEAVER, E. W. and MOUNCE, G. R. Method and apparatus for the automatic control of machinery. *U.S. Patent* 2, 475, 245, October 14, 1949

57 LEVIN, A. A. and OKHLYAND, A. B. Transport systems of automatic machine lines (Transportniye sistemy avtomaticheskikh stantochnikh linii). *Avtomat. Telemekh., Moscow*, 1952, 13(3), 339–56

58 MIKHAILOV, N. I. Improving and getting full value from automatically controlled series of machine tools (Naladka i osvoenie avtomaticheskikh stanochnikh linii). *Avtomobilnaya Promyshlennost, Moscow*, January, 1949, (1) 9–10

59 PAQUIN, G. R. Principles of automatic sorting and feeding. American Society of Tool Engineers, 21st Annual Meeting, 1953. Paper No. 21T5–1

60 RYLANDER, A. E. Elements of automatic stock feeds. *Tool Engr*, January, 1951, 26, 51–8

61 SNOWBERGER, J. E. Transfer equipment stresses flexibility, cuts cost (Willys-Overland Motors Inc., Toledo, Ohio). *Iron Age*, September 11, 1952, 170, 156–7

62 TANGERMAN, E. J. Automation combines standard lathes. *Amer. Mach., N.Y.*, March 29, 1954, 98, 110–13

63 TEMCHIN, G. I. Methods of designing and standardizing of multiple tool machine operations (O metodike proektirovaniya i pormirovaniya mnogoinstrumentnykh stanochnykh operatsii). *Avtomobilnaya i Traktornaya Promyshlennost, Moscow*, 1953, (10), 21–30; (12), 14–23

64 VIKHMAN, V. S. Automatisation of the technical control of mass-produced machine parts (Avtomatizatsiya tekhnicheskogo kontrolya massobykh detalei mashinostroeniya). *Avtomat. Telemekh., Moscow*, 1952, 13(4), 472–83

65 VLADZIEVSKII, A. P. The probability of law of operation of automatic lines and internal storage in them (Veroyatnostny zakon raboty i bnutrenniye zapasy avtomaticheskikh linii). *Avtomat. Telemekh., Moscow*, 1952, 13(3), 227–81 *(Copy of translation available on loan on application to D.S.I.R., Records Section, 5–11 Regent Street, London, S.W.1)*

66 WOOLLARD, F. G. The advent of the automatic transfer machines and mechanisms. *J. Instn Prod. Engrs*, January 1953, 32(1), 18–36, 46

CONTROL OF MACHINE-TOOLS

67 Convair Division (General Dynamic Corporation) plans its automatic milling machine. *Control Engineering*, June, 1955, 2(6), 15

68 Magnetic filmed data controls machine tools. *Industrial Laboratories*, June, 1955, 6(6), 69

69 Modern machine tool trends. *McGraw-Hill Dig.*, December, 1955, 9(12), 13–15

70 Magnetic-tape control of machine tools. *Mach. Tool Rev.*, July–August, 1954, 42(251), 89–91

71 Numerically controlled milling machine. Part 2. (Final report to the U.S. Air Force on construction and initial operation). Massachusetts Institute of Technology—Servo-mechanisms Laboratory, May, 1953. (*Available on request from D.S.I.R. Technical Information and Documents Unit, 15 Regent Street, London, S.W.1*)

72 Electronic positioning—digital methods for automatic control of machine-tools *Wireless World*, January, 1955, 61(1), 25–7

73 BOOTH, R. H. The computer—electronics' contribution to production. Institution of Production Engineers. Report of the Conference held at Margate, 16th to 19th June, 1955, 49–56

74 FENEMORE, R. W. and BORLEY, C. R. Automatic control of machine tools. *Research, Lond.*, September, 1955, 8(9), 351–6

75 KAPLAN, J. Y. Automation of machine tools. American Society of Tool Engineers, 21st Annual Meeting, March, 1953. Paper No. 21T18

76 KLIEVER, W. H. Automatic machining—a view and a preview. *Control Engineering*, September, 1955, 2(9), 112–22; October, 1955, 2(10), 84–9

77 PEASE, W. An automatic machine tool. *Sci. Amer.*, September, 1952, 187(3), 101–15

78 STOCKER, W. M. and EMERSON, C. D. Numerical control; what it means to metalworking. *Machinist*, December 10, 1954, 98(50), 2185–200

79 WILLIAMSON, D. T. N. Computer-controlled machine tools. Institution of Production Engineers. Report of the Conference held at Margate, 16th to 19th June, 1955, 144–53

E. THE PROCESS-INDUSTRIES

80 Automatic printing and cutting. *Automation*, October, 1955, 2(10), 46–49

81 Principles of the design of commercial apparatus of automatic control and regulation. *Elektrichestvo, Moscow*, 1951, (2), 87–9

82 Continuous infra-red analyzers for petrochemical quality control. *Industrial Laboratories*, June, 1955, 6(9), 57

83 Handbook of measurement and control. *Instruments and Automation, Pt. 2*, December, 1954, 27(12) (Entire issue)

84 The "weigh" of the world. *The Tabulator* (Hollerith), No. 85, 18–19

85 Instrumentation for the process industries. *7th Annual Symposium*—Department of Chemical Engineering, Agricultural and Mechanical College, Texas. Instruments Publishing Co., Pittsburgh, 1952. 66 pp.

86 The instrument manual. United Trade Press, London, 1953.

87 Regelungstechnik (Vorträge des VDI/VDE-Lehrganges in Bonn 1953 und Essen, 1954). Deutscher Ingenieur-Verlag, Düsseldorf; VDE-Verlag, Wuppertal and Berlin, 1954

88 AYRES, E. An automatic chemical plant. *Sci. Amer.*, September, 1952, 187(3), 82–96

89 BALLS, B. W. and ISAAC, A. H. Automatic process control and chemical engineering. *Trans. Instn chem. Engrs, Lond.*, 1955, 33(3), 177–86

90 BRIMELOW, E. I. Continuous gauging—a step toward the automatic factory. *The Times Science Review*, Summer, 1955, 13–14, 16

91 DERR, W. A. and HYDE, M. A. Remote operation of pipe-line pumping stations. *Trans. Amer. Inst. elect. Engrs (Applications and Industry)*, September, 1954, (14), 190–8

92 DURR, A. Elements of electro-hydraulic control. *Machinist*, March 20, 1954, 98, 477–86

93 ECKMAN, D. P. Industrial instrumentation. Wiley, New York, 1950

94 EVANS, J. C. *et al.* Continuous pneumatic gauging of a material in wire or thread form. *Trans. Soc. Instr. Tech.*, June, 1950, 2(2), 34–49

95 GEE, R. E. *et al.* Use of computers in kinetic calculations. *Chem. Engng Progr.*, 1954, 50, 497–502

96 GOLDSTEIN, W. A. Automatic control of batch processes. *Trans. Instn chem. Engrs, Lond.*, 1955, 33(3), 199–204

97 GREEN, A. Capacitance in automatic control. *British Communications and Electronics*, November, 1955, 2(11), 61–7

98 HARTLEY, Sir Harold. Chemical engineering—the way ahead (Presidential address). *Trans. Instn chem. Engrs, Lond.*, 1955, 33(1), 20–6

99 JANSSEN, J. H. L. Automatic controller's organic functions in plant. *Ingenieur, 's Grav.*, November, 1952, 64(46), 125–31

100 JANSSEN, J. H. L. A practical guide to plant controllability. *Control Engineering*, November, 1955, 2(11), 58–65

101 LOMAKIN, I. L. On the problem of classification of control devices in the chemical industry (K voprosu o klassifikatsii obektov regulirovaniya v khimicheskoi promyshlennosti). *Avtomat. Telemekh., Moscow*, 1952, 13(6), 629–36 (*Copy of translation available on loan on application to ASLIB, 4 Palace Gate, London, W8*)

102 MCMILLAN, J. The dynamics of process plant. *Trans. Instn chem. Engrs, Lond.*, 1955, 33(3), 168–76

103 MEDLOCK, R. S. Fundamentals of automatic process control. *Trans. Instn chem. Engrs, Lond.*, 1955, 33(3), 156–67

104 PUTMAN, J. L. Development in thickness gauges and allied instruments. *Process Control and Automation*, November, 1955, 2(11), 417–21

105 THOMPSON, W. E. Beta-ray thickness gauges in industry. *Process Control and Automation*, March, 1955, 2(3), 92–94

106 YOUNG, A. J. Prerequisites of the automatic chemical factory. Institution of Production Engineers. Report of the Conference held at Margate, 16th to 19th June, 1955, 180–90

107 YOUNG, A. J. An introduction to process control system design. Longmans, Green, London, 1955. 378 pp.

F. PROCESSING OF DATA

108 Rambles through Binland and Electronia. British Tabulating Machine Co., London, undated

109 Electronic computer used in locating oil. *Industrial Laboratories*, July, 1955, 6(7), 97

110 APPEL, R. W. *et al.* Electronic business machines (Non-technical survey of present and future position) (Report to Professor Doriot). Harvard Graduate School of Business Administration, June, 1953. 63 pp.

111 BOWDEN, B. V. Electronic processing of data for management (Paper presented at the B.I.M. National Conference, Harrogate, November, 1955). *Process Control and Automation*, November, 1955, 2(11), 425

112 CLIPPINGER, R. F. Economics of the digital computer. *Harvard Business Review*, January–February, 1955, 33(1), 77–88

113 DAVIS, H. M. Mathematical machines. *Sci. Amer.*, April, 1949, 180(4), 29–39

114 HUGGINS, P. Statistical computers as applied to industrial control. *J. Brit. Instn Radio Engrs*, July, 1954, 14(7), 309–21

115 LESSING, L. P. Computers in business. *Sci. Amer.*, January, 1954, 190(1), 21–5

116 ROBERTS, F. and NORRIE, G. O. Electronic business machines—a critical review. *British Communications and Electronics*, July, 1955, 2(7), 40–5

117 SMITH, W. W. Impact of the computer on methods (Office Management Series No. 136, The impact of computers on office management, pp. 3–16). American Management Association, New York, 1954

G. LARGE-SCALE APPLICATIONS

118 Pushbutton line for ammunition (Pressed Steel Car Co.) (Rockford, Ill. Ordnance Plant). *Business Week*, September 26, 1953, 68

119 Man-hours off 70% in this almost automatic foundry (Crane Co.). *Fact. Mgmt*, October, 1954, 112(10), 90–1

120 Project on modular design of electronics and mechanized production of electronics. Report. Summary of modular design of electronics and mechanized production of electronics. **Vol. 1**—PB-111275: Techniques for converting from conventional design of electronics to modular design of electronics. **Vol. 2**—PB-111276: Hand fabrication technique and photographic processing for modular design of electronics. **Vol. 3**—PB-111277: Mechanized production of electronics. **Vol. 4**—PB-111278: Manufacturing cost determination. **Vol. 5**—

PB–111315. National Bureau of Standards (Distributed by U.S. Department of Commerce, Business & Defence Services Administration, Office of Technical Services, Washington, D.C.)

121 A plant is born (Plymouth Qualimatic V–8 Engine Plant). *Tooling and Production*, October, 1955, 21(7), 81–250

122 BEAN, N. L. Automation—outstanding methods of increasing production. *Mech. Engng, N.Y.*, May, 1949, 71(5), 389–90, 394

123 BRADLEY, W. F. How Renault has modernized its plant to triple output. *Automot. Industr., N.Y.*, July 15, 1948, 99, 24–5, 60, 62, 64

124 DIEBOLD, J. *et al.* The automatic factory—a practical possibility? Pt. 1. The approach to automation. *Machinist*, March 15, 1952, 96, 381–8. Pt. 2. Layout study for an automatic piston factory. *Machinist*, April 12, 1952, 96, 537–44

125 ERIVANSKY, A. A Soviet automatic plant. Foreign Languages Publishing House, Moscow, 1955. 86 pp.

126 GRIFFITHS, F. and HOLBECHE, H. W. Automation at the Austin motor works. *Instrum. Pract.*, March, 1955, 9(3), 252–4

127 HAMMOND, R. Continuous production of building board (Bartrev). *Process Control and Automation*, March, 1955, 2(3), 95–9

128 HURSH, S. R. The Pennsylvania Railroad (Exhibit and testimony before the Congressional Sub-Committee on Economic Stabilization, showing the implication and significance of automation in major switching yards of the railroad industry. October 27, 1955). Pennsylvania Railroad Company, Philadelphia.

129 NIKITIN, S. A. Automatic factory for the production of automobile engine pistons (Zavod-avtomat po proizvodstvu porshnei avtomobilnikh dvigatelnei). *Avromobilnaya i Traktornaya Promyshlennost, Moscow*, 1951, (3), 16–27 (*Translation available on loan from D.S.I.R., Records Section, 5–11 Regent Street, London, S.W.1.*)

130 PROKOPOVICH, A. E. Automatic piston works. (Public lecture delivered at the All-Union Society for the Propagation of Political and Scientific Knowledge) (Zavod avtomat), Moscow, 1951. (*Translation available on loan from D.S.I.R., Records Section, 5–11 Regent Street, London, S.W.1*)

131 SARGROVE, J. A. New methods of radio production. *J. Brit. Instn Radio Engrs*, 1947, 7(1), 2–33

H. SPECIFIC APPLICATIONS

COAL AND GAS INDUSTRIES

132 Report of the Committee on Air Pollution, Cmd. 9322, 1954. H.M. Stationery Office, London.

133 Practical smoke abatement. *Engineering, Lond.*, December 17, 1954, 178, 793–4

134 Automatisation of production methods in the coal-mining industry (Avtomatizatsiya proizvodstvennikh protsessov v ugolnoi promyshlennosti). *Mekhanizatsiya Trudoemkikh i Tyazhelykh Rabor, Moscow*, November, 1951, 5(11), 9–10

135 ANTONOVSKAYA, M. A. *et al.* Complex automatisation of coal mines (Kompleksnaya avtomatizatsiya na ugol'nuikh shakhtakh). Ugoltekhizdat, Moscow, Kharkov, 1950. 170 pp.

136 BERSTEL, V. N. Perspectives of the automatization of production processes in the coal industry (Perspektivy razvitiya avtomatizatsii proizvodstvennykh protsessov v ugol'noi promyshlennosti). *Ugol, Moscow*, August, 1950, **25**(8), 27–8

137 BRIDGES, J. and DAVIES, E. G. An automatic system of control of boiler house auxiliaries. *G.E.C. Journal*, October, 1954, **21**(4), 231–5

138 BURKE, S. A. and SPARHAM, G. A. Automatic control systems for the coal feed of gas producers. *J. Inst. Fuel*, November, 1951, 24(140), 257–64

139 CLAY, G. P. The economic level of instrumentation in boiler plants. *Instrum. Pract.*, December, 1955, **9**(12), 1164–9

140 IVE, G. A. G. Electronics as an aid to smoke abatement. *British Communications and Electronics*, December, 1955, **2**(12), 64–5

141 LINFORD, A. Automatic control of gas producers. *Pwr and Wks Engng*, December, 1952, 47, 419, 444–5

METAL-PROCESSING

142 BRADY, T. W. Photoelectric controls in a rolling mill. *Engineering, Lond.*, December 17, 1954, **178**(4638), 788–9

143 CHELYUSTKIN, A. B. and ROZENMAN, E. A. The automatic operating of rolling mills (Avtomaticheskoe uprovlenie prokatnymi stanami). Moscow. 1950. 484 pp. (Reviewed by L. B. Geiler in *Elektrichestvo, Moscow*, 1951, (3), 94)

144 DARNTON, T. E. Automation in forging and heat treating (Oldsmobile Division, General Motors Corporation). *Automot. Industr., N.Y.*, May 1, 1950, **102**, 67–70

145 THORING, M.W. Physics and furnaces. *The Times Science Review, No.* 5, Autumn, 1952, 4–7

GENERAL ENGINEERING PROCESSES

146 Precision control of sizing on centreless grinding machines—pushbutton or automatic operation. *Engineering, Lond.*, December 24, 1954, **178**(4639), 837

147 Automation produces refrigerators for Westinghouse. *Mach. Tool Blue Bk*, May, 1954, 186–90, 192

148 Fully automatic extrusion plant (Aston Chain & Hook Co., Erdington, Birmingham). *Mass Prod.*, June, 1952, 28(6), 78–83

149 BORKUNOV, N. I. and CHELISHCHEV, B. A. Automatization of spot welding of the hydraulic coupling rotor in motor car ZIM (Avtomatizatsiya tochechnoi svarki rotorov gidromufty avtomobilya ZIM). *Avtomobilnaya i Traktornaya Promyshlennost, Moscow*. May, 1951, (5), 15–18

150 MOOERS, A. B. Transfer devices extend automation in press shop (Buick Motor Division, Flint, Michigan). *Iron Age*, August 26, 1954, **174**(9), 101–3

151 SCOTT, D. Russians apply automation in bearing manufacture. *Machinist*, April 10, 1954, **98**, 601–6

MOTOR-VEHICLE INDUSTRY

152 Transfer machinery: the production of cylinder blocks for Consul and Zephyr engines. *Auto. Engr*, July, 1951, **41**, 255–64

153 Centreless grinding: an interesting Scrivener development for transfer machines. *Auto. Engr*, August, 1951, **41**, 303–4. (Also in : *Machinery*, June 14, 1951, **78**, 1009–11, and *Mach. Tool. Rev.*, July–August, 1951, **39**, 87–90)

154 Cylinder head machining: production methods for Ford Zephyr and Consul engines. *Auto. Engr*, October, 1951, **41**, 373–8

155 Production mechanization and automatization in the motor car and tractor industry (Zavod-avtomat po proizvodstvu porshnei avtomobilnikh dvigatelei). *Avtomobilnaya i Traktornaya Promyshlennost, Moscow*, March, 1951, (3), 1–2

156 Machining Morris-Oxford gearboxes on an Archdale transfer machine. *Machinery*, January 10, 1952, **80**, 46–58

157 GESCHELIN, J. 80 Oldsmobiles an hour. *Automot. Industr., N.Y.*, April 1, 1950, **102**, 42–4, 70, 72

158 GESCHELIN, J. Buick's new self contained plant for producing V-8 engines. *Automot. Industr., N.Y.*, 1953, **108**, February, 56–9; March, 32–6; June, 50–4

159 PERRY, H. W. Automation: recent developments at Ford Motor Co., U.S.A. *Auto. Engr*, August, 1954, **44**, 323–5

160 WINKLEMAN, C. and DILLEY, R. Ford's automated engine plant. *Fact. Mgmt*, December, 1952, **110**(12), 93–108

PETROLEUM-REFINING

161 Automatic control in the petroleum industry (Vtoraya konferentsiya po avtomatizatsii neftyanoi promyshlennosti). *Avtomat. Telemekh., Moscow*, 1950, **11**(4), 286–8

162 ANDERS, V. R. and PANTAEV, N. F. Automatic regulation of petroleum treatment. (Avotmaticheskoe regulirovanie protsessov pererabotki nefti). Gostoptekhizdat, Moscow-Leningrad, 1951. 228 pp.

163 POLLARD, A. Automatic control of distillation processes. *Chemical and Process Engineering*, November, 1954, **35**(11), 339–42, 347; January, 1955, **36**(1), 10–16

164 REDDING, R. J. Electronic process control in an oil refinery. *Instrum. Pract.*, July, 1952, **6**(9), 597–603

165 STEWART, L. Electronically controlled refinery. *Instruments and Automation*, December, 1954, **27**(12), 1948–50

CHEMICALS

166 The automatic chemical laboratory. *Discovery*, December, 1955, **16**(12), 529–30

167 Chemical developments in the U.S.A. (Automatic control of pulp mills). *Industr. chem. Mfr.*, February, 1955, **31**(361), 86

168 Progress in polythene bottle manufacture. *Plastics, Lond.*, August, 1954, 250

169 FLEMING, A. E. Level control. *Instruments and Automation*, May, 1955, **28**(5), 899–915

170 GRAVENSTRETER, P. R. and LAYTON, R. E. Trends in automation: electronic tinning. *Trans. Amer. Inst. elect. Engrs (Applications and Industry)*, July, 1954, **74**(Pt. 2)(13), 97–101

171 GREEN, J. R. Automatic control of glass forehearths. *Bull. Amer. ceram. Soc.*, July 15, 1954, **33**, 204–12

172 SIMONS, W. H. Modern electroplating plant. *Metal Ind.*, Lond., April 29, 1955, 86(17), 333–8

173 SMIRNOV, V. S. More extensive introduction of automatic control and measuring apparatus in the pulp and paper industry (Shire vnedryat avtomatiku i kontrolno-izmeritelnuyu apparaturu v tsellyulozno-bumazhnuyu promyshlennost). *Bumazhnaya Promyshlennost, Moscow*, March/April, 1951, 26(2), 45–6

174 UNDERWOOD, N. E. Automatic control in the pulp and paper industry. *Trans. Instn. chem. Engrs, Lond.*, 1955, 33(3), 210–17

175 WALTERS, N. E. Controlling continuous work processes. *Automation*, September, 1955, 2(9), 34–9

PROCESSING OF DATA

176 A nation of clerks ? (Editorial on the electronic office). *British Communications and Electronics*, February, 1955, 2(2), 37

177 News item on installation of second Univac electronic computer by U.S. Steel. *Chem. Engng News*, January 10, 1955, 33(2), 126

178 Data processor at work: Monsanto demonstrates first industrial use of IMB 702 for accounting, scientific, and technological problems. *Chem. Engng News*, April 25, 1955, 33(17), 1764, 1766

179 Problems solved in seconds. *Ethyl News*, March–April, 1955, 4–6

180 Speeding airline booking. *Mod. Transp.*, March 14, 1953, 69(1772), 11

181 New "all-transistor" calculator may surpass electronic models (I.B.M.) *New York Times*, October 8, 1954.

182 The scope for electronic computers in the office. (Paper submitted by Leo Computers Ltd. to the Office Management Association's Conference, May, 1955). Office Management Association, London, 1955

183 Erma—electronic bookkeeper. *Research for Industry* (Stanford Research Institute), October, 1955, 7(9)

184 BURCH, B. F. The computer at work on payrolls (*Office Management Series No.* 136, The impact of computers on office management, pp. 16–25). American Management Association, New York, 1954

185 CARR, W. J. Solving scientific problems. *Control Engineering*, January, 1956, 3(1), 63–70

186 COOLEY, E. F. Computer methods and application: a case study (*Office Management Series No.* 136, The impact of computers on office management, pp. 41–6). American Management Association, New York, 1954

187 GLENDINING, R. Electronic accounting. *The Accountant*, February 5, 1955, 132(4181), 148–50

188 PINKERTON, J. M. M. and KAYE, E. J. Leo (Lyons Electronic Office). *Electron. Engng*, July, 1954, 26(317), 284–91

189 VANSELOW, A. C. Programming the computer for clerical production (*Office Management Series No.* 136, The impact of computers on office management, pp. 26–40). American Management Association, New York, 1954

I. IMPLICATIONS FOR LABOUR

190 One-fifth of metal-working plants use automation. *Amer. Mach.*, August 29, 1955, **99**(18), 158–9

191 Automation and other technological advances: a panel session (*Manufacturing Series No.* 205). American Management Association, 1953

192 Medical Research Council. Industrial Health Research Board. *Emergency Reports:* No. 1. Industrial health in war (1940); No. 2. Hours of work, lost time and labour wastage (1942). H.M. Stationery Office, London

193 Handbook of human engineering data for design engineers (2nd edn) (U.S. Navy, Special Devices Center, *Technical Report S.D.C.* 199-1-2-1951). Tufts College, Medford, Mass. Institute for Applied Experimental Psychology, 1951

194 Automation and technological change (Sub-committee on Economic Stabilization to the Joint Committee on the Economic Report, Congress of the United States. Hearings, October, 1955; Report, November, 1955). U.S. Government Printing Office, Washington, D.C., 1955

195 BALDWIN, G. B. and SCHULTZ, G. P. Automation: a new dimension to old problems. *Monthly Labor Review*, February, 1955, 78(2), 165–9

196 BELLO, F. Fitting the machine to the man. *Fortune*, November 8, 1954, **50**(5), 134–7, 148, 152, 154, 156, 158

197 COX, D. Women's attitude to repetitive work (Report No. 9). National Institute of Industrial Psychology, London, 1953. 59 pp.

198 FRIEDMANN, G. Automation and industrial work. *Appl. Anthrop.*, Summer, 1954, 7–15

199 GIBBS, C. B. Psychological aspects of machine design. *The Manager*, September, 1955, 23(9), 668–72

200 STEWART, R. Management succession. *The Manager*, August, 1955, **23**(8), 579–82

201 VAN AUKEN, K. G. The introduction of an electronic computer in a large insurance company (*Studies of Automatic Technology, No.* 2). U.S. Department of Labor. Bureau of Labor Statistics, October, 1955

202 WADDELL, H. L. Progress in automatic production. *Mech. Engng, N.Y.*, March 1953, 75(3), 207–10

203 WALKER, C. R. and GUEST, R. H. The man on the assembly line. Harvard University Press, 1952. 175 pp.

204 WEINBERG, E. A case study of a company manufacturing electronic equipment (*Studies of Automatic Technology, No.* 1). U.S. Department of Labor. Bureau of Labor Statistics, October, 1955

205 WELFORD, A. T. *et al.* Skill and age —an experimental approach. Oxford University Press, 1950. 161 pp.

206 WILSON, A. T. M. Some contrasting socio-technical production systems. *The Manager*, December, 1955, 23(12), 979–86

207 WYATT, S. and MARRIOT, R. Nightwork and shift changes. *Brit. J. industr. Med.* 1953, **10**, 164–72

APPENDIX V

SUGGESTED SUBJECTS FOR RESEARCH ON SOCIAL AND ECONOMIC ASPECTS

THE NEED for more facts on the social and economic effects of automation has been stressed throughout this Report and possible subjects for investigation are listed in the left-hand column below. Research completed or in progress is listed in the right-hand column, but much of it is only relevant in part to automation.

SUBJECT	RESEARCH
1. *Managerial decisions to innovate*	
The reasons why managements adopt or fail to adopt automation and other new techniques. (*a*) The comparative costs of products manufactured on different scales by automatic and non-automatic methods (including those advantages and disadvantages of automation that cannot easily be expressed in financial terms). (*b*) Other factors, such as business opinions and the availability of capital or specialised plant and instruments or specialist workers or consultants.	Considerable general research into technical innovation forms part of the economic and social research programmes sponsored by the Department of Scientific and Industrial Research. Most of the relevant projects do not deal specifically with automation but they will increase knowledge of the factors that govern the rate of technical innovation.
2. *Manpower requirements*	
(*a*) Future requirements of scientific and technical manpower.	(*a*) A survey is being made by the Ministry of Labour and the D.S.I.R. but it does not deal specifically with automation. (See pages 53–4).
(*b*) The existing uses of trained manpower, and the extent to which present training schemes meet modern needs.	(*b*) Political and Economic Planning (P.E.P.) has been investigating the employment of graduates in industry (page 54, footnote)*.
(*c*) The recruitment, training and future supply of key occupational groups, such as electronics technicians.	(*c*) Bedford College (University of London) and the University of Bristol are investigating apprenticeship†.
	(*d*) A survey of electronic technicians has been made in the U.S.A.[32].

SUBJECT	RESEARCH
3. *Impact on management*	
(*a*) The forms of management structure and organization that are most effective with automatic processes.	(*a*) Work is being done by the South-East Essex Technical College and by the University of Edinburgh (page 60)*.
(*b*) The new techniques of management required by automation; in particular how certain statistical techniques that are used in the study of operations can make automatic machine-lines more efficient.	(*b*) These techniques are being investigated in the U.S.S.R.[47, 53, 58, 63, 65]
(*c*) Methods of planning manpower requirements (for example, the planning of innovations to coincide with natural fluctuations in the labour force). Training requirements.	
4. *Impact on employment and skills*	
(*a*) How far labour has been displaced by automation in individual firms. Methods of dealing with redundancy.	
(*b*) (Complementary to (*a*)). Analysis of the potential field for automation, industry by industry. Forecasting of manpower requirements.	
(*c*) Changes in the occupational structure of individual firms due to automation. The new skills to which automation gives rise.	(*c*) Work is being done at the Universities of Liverpool (page 69),* and Cambridge (page 68).
5. *Psychological aspects of the design of machines*	
(*a*) How information given by instruments and in other ways can be presented so as to increase efficiency and reduce fatigue. (*b*) The efficiency of the human operator as a machine-minder or process-monitor.	Much relevant work has already been published (page 75, footnote). In this country the work of the Applied Psychology Unit of the Medical Research Council at Cambridge is particularly relevant.
6. *Satisfaction from work*	
(*a*) The social implications of shift-work.	(*a*) Research is being done at the University of Sheffield (see page 57).† The already noted research projects at the Universities of Cambridge and Liverpool are partly relevant. The University of Cambridge is also studying the economics of shift-working. (page 57).†

SUBJECT	RESEARCH
(*b*) Attitudes and satisfactions in process-monitoring.	(*b*) Considerable study has been made of the repetitive-worker in mass-production, but little of the process-monitor.
(*c*) The structure of working groups on automatic processes.	(*c*) The research project at Cambridge University is partly relevant (page 68).

* These projects have been sponsored by the Department of Scientific and Industrial Research and financed from Conditional Aid funds derived from U.S. economic aid.

† These projects have been sponsored by the Ministry of Labour and National Service and financed as those in the first footnote above.

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